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Rayon Reports

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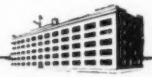

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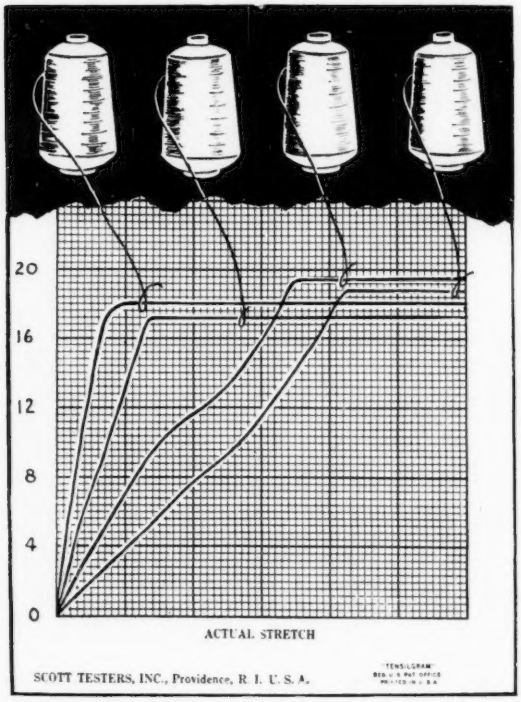

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TEXTILE RESEARCH JOURNAL

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The Fine Histology of the Keratin Fibers

Joel Lindberg, E. H. Mercer,* Bo Philip, and Nils Gralén

Swedish Institute for Textile Research, Gothenburg, Sweden

Introduction

In recent years the application of electron microscopy and of improved optical microscopy to the study of the keratin fibers—wool and hair—has led to considerable advances in our knowledge of their histology. In particular, much has been learned about the structure of the cuticle, which had not proved easy to study by using the earlier methods. However, some uncertainty exists as to the precise picture of the structure of the fiber which has emerged, and we wish, therefore, to present a summary of the new findings, to indicate some of their practical implications, and also to emphasize the need for adopting a definite nomenclature for future discussion of the subject.

The classical histology distinguished three regions in the hair—cuticle, cortex, and medulla [14]. The medulla is usually absent from fine hairs and wools, and most workers have tried to simplify their problems by using non-medullated fibers. Hence, little of importance has been added to our knowledge of the medulla recently, and our remarks are confined to the cortex and the cuticle. The new developments are concerned largely with the clarification of details already suggested by earlier work, but some very important hitherto unobserved structures have been reported. Both the cuticle and the cortex are cellular structures, and a variety of procedures have been described which lead to a division of the fibers into their component cells. Such procedures have been used by most investigators.

The Cuticle

The cuticle was previously regarded simply as a sheath of flattened, overlapping cells or scales closely investing the cortex. Its cellular character and its relation to the cortex may best be understood from an examination of its development in the hair follicle [7, 14]. It is still possible, however, in the final, flattened, and hardened scale to demonstrate both an internal cavity and the remnants of a nucleus [4, 7]. The ratchet action of the external surface makes the hair rougher in the tip-root than in the root-tip direction, and the importance of this property, both to the animal in assisting grooming and in technology as the cause of felting, has frequently been emphasized. A desire to modify the felting power of wool has been one of the main reasons for the extensive study of the cuticle.

Electron-microscope studies chiefly have led to the view that the cuticle is a more elaborate struc-

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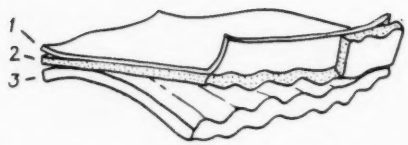

FIG. 1. *The composite structure of the* cuticle *of animal hair:* (1) *epicuticle;* (2) *exocuticle;* (3) *endocuticle. The under-surface may also be complex, but there is no definite evidence of this; a cement substance probably covers the lower surface.*

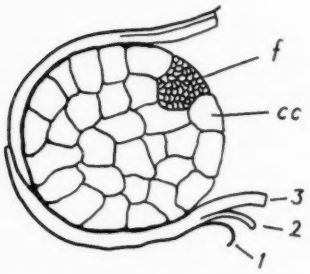

FIG. 2. *Cross section of non-medullated wool fiber—purely diagrammatic to show relative positions of the components of the cuticle* (cf. *Figure* 1), *the cortical cells* (cc) *and fibrillae* (f) *of the cortex.*

ture of several more or less distinct components. Proceeding from the outside of the fiber inward (see Figures 1 and 2), the following have been described: (*a*) a very thin *epicuticular membrane* * covering the whole of the surface and thus forming the external surface of the fiber, (*b*) an *exocuticle* layer, and (*c*) an *endocuticle*.† The intermediate layer, the exocuticle, was first pointed out by Mercer and Rees [17], who refer to it as K_1. The endocuticle consists of the flattened scale remnant which is the usual result of tryptic digestion, and is often referred to as the "cuticle" (meaning the whole cuticle). The relation of these three layers is shown diagrammatically in Figure 1. It is not known whether the other side (inward) of the scale cells is similarly elaborate, but there is no evidence as yet for this. Cementing material may be assumed to be between all the layers mentioned and the cortex.

Evidence for the Multiple Structure of the Cuticle

The evidence for the existence of the epicuticle is simple and direct [12, 13]. Wool fibers are lightly chlorinated, washed, and shaken in water. The chlorine preferentially attacks the intermediate layer (see below), loosening the epicuticle, which then may be shaken off (see Figure 5). In the aqueous suspension are found the characteristic thin membranes such as are illustrated in the original papers [12, 13] and the accompanying paper [16]. The manner of preparation is sufficient to establish the fact that the films must lie on the outside of the fibers. The epicuticle, as seen in the electron microscope, appears as a thin, uniformly thick (about 100 A.) film falling easily into folds. Its most remarkable property, which we suppose is associated with its role as a protective element to the fiber, is its chemical stability. It is not dissolved by chlorine, alkalies, strong acids, sodium sulfide (which has a strong action on true keratin), or enzymes. It was, in fact, first isolated from solutions of wool in sodium sulfide [13]. Such observations indicate that the epicuticle is not keratin. Its origin is still a matter for speculation, but its chemical composition is under investigation at the Swedish Institute for Textile Research. Some examples of its importance in the technology of wool are given below. It is possible that other such membranes may occur in other tissues.

The existence of the two layers, exocuticle and endocuticle, was concluded from an electron-microscopic comparison of the appearance of unaltered scales and scale residues obtained by tryptic digestion [17]. The unaltered scale presents a smooth surface in replicas [15, 24] and is relatively uniform in thickness. Scale remnants in tryptic digests possess an uneven, etched surface whose characteristics may be judged from the examples given by Mercer and Rees [17] and also by Gorter and Houwink [5]. The smooth surface seems to be due to the overlying epicuticle fastened to the underlying, resistant residue by the less resistant intermediate exocuticle, which is removed by the enzyme or other degrading agents to reveal the unevenly surfaced residue. Little is known about the nature of the intermediate layer, but its digestibility by trypsin shows that it is a protein. Probably it is a "keratin" less extensively cross-linked than the inner fraction of the cuticle.

* The "*epicuticle*" was isolated by Lindberg, Philip, and Gralén [13], but a number of earlier observations pointed to its existence [8, 17, 25].

† The nomenclature follows that which is customarily used in connection with the insect cuticle.

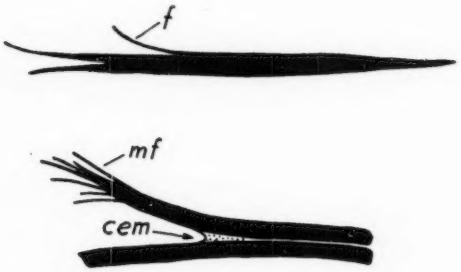

FIG. 3. *Diagram to illustrate the nomenclature employed to describe the fine histology of the cortex of animal hairs. Cortical cell (as released), from fine Merino wool by tryptic digestion. The cell consists of a bundle of fibrils, one of which is shown* (top) *at* f *splitting off the cell. Two fibrils* (bottom) *are shown enlarged. The fibrils (or macrofibrils) are held together by a cortical cement* (cem) *and are composed of finer fibrils, which may be called microfibrils* (mf).

Structures Between the Cuticle and the Cortex

In a number of papers (those by Reumuth [20], Lehmann [9, 10], and Elöd and Zahn [2]) attempts have been made to show that a hitherto unrecognized membrane, the "*subcutis*," * lies between the cuticle and cortex. Such a component, amounting, according to Elöd and Zahn, to more than 5% of the fiber weight, would be of great importance, and the evidence of its existence must be carefully considered.

We have repeated the experiments of the German workers and have obtained precisely the same results. However, we have found it possible to explain their findings in terms of the several components of the cuticle. This question is fully treated in the accompanying paper [16], and in view of the conclusions reached there the "subcutis" will not be described here as a distinct component of the fiber. The possibility of the existence of a cementing layer between the cortex and the cuticle has been discussed earlier in this paper, but it cannot be considered to be experimentally verified.

The Cortex

Recent research has somewhat elaborated but not fundamentally altered our views of the histological structure of the cortex. Some excellent pictures of the cross sections of wool fibers by Reumuth [20] show the cortical cells closely packed as in Figure 2. Cell membranes appear to be present. Somewhat similar cross sections by Hock, Ramsay, and Harris [7] and Rudall [22] show the same arrangement of the cells, and establish the fact that these are not flat in section, although this appearance is often given by isolated cells. Since the cortex is resolved into cells by enzymes, it is usual to suppose that an intercellular cement exists, of similar character to that postulated to be present in the cuticle and probably also between the cuticle and the cortex.

The long, tapering cortical cells have been known, since von Nathusius [19], to consist of closely packed fibrils. Optical micrographs showing these fibrils within the cells have been obtained [9, 20], but the electron microscope shows this fibrillar structure most clearly and shows also that the fibrils adhere to each other by reason of the extension of a cement material between them (Figure 3, [18]). The fibrillae seem to be the only fibrous elements in the fiber, and, being also characterized by more or less indefinite resistance to enzymic digestion, may be regarded as composing the truly fibrous keratin. They are undoubtedly the components of the fiber responsible for the x-ray fiber pattern. The cement substance seems to be a protein but is not fibrous [18] and is not resistant to digestion. The fibrils, in turn, are composed of smaller fibrils (see Figure 3), visible only in the electron microscope, which have been termed microfibrils or protofibrils [3, 5, 6, 26]. The term "protofibrils" has been preferred by Farrant, Rees, and Mercer [3] because these fine fibrils seemed to be formed from a string of particles. Until the existence of this substructure has been confirmed beyond doubt, the term "microfibrils" may be preferred [5].

Practical Importance of the New Fiber Histology

The more complete knowledge of the histological complexity of hair and wool fibers certainly emphasizes the difficulties associated with the interpretation of the results of experiments, but, on the other hand, particularly in the case of reactions in which the cuticle plays a part, it has helped to clear up some problems and may point the way to some practical advances. A few suggestions are discussed below.

Diffusion Phenomena—Dyeing

The cuticle has been recognized as a limiting factor in the penetration of large molecules into the

* Also called the "subepidermicula" and the "Zwischenmembran."

fiber—*e.g.*, in the case of dyes [21]. However, on account of its position as the outermost layer of the fiber, its continuous and coherent structure, and its chemical inertness, the *epicuticle* probably makes the greatest contribution to the impermeability of the cuticle. The difficulties of wetting sound fibers, certain problems of penetration of dyes and other reagents, and the resistance of hair to enzymic digestion are phenomena which we suggest are associated with the presence of the epicuticle. Remarkable changes in the wettability of wool, its dyeing properties, and the ease of scouring may be produced by treatments—*e.g.*, with alcoholic caustic potash solutions or gaseous chlorine (moisture present)—which increase the permeability of the epicuticle or loosen and remove it. The progressive changes in the rate of absorption of dyes produced in the course of manufacturing processes, noted by Royer, Millson, and Amick [21], may be explained by the progressive impairment in the barrier offered by the epicuticle. End staining and patchy and tippy dyeing are other effects likely to be conditioned by the state of the epicuticle (see Figure 4) and can be overcome by uniformly damaging the epicuticle.

A new approach to the problems of dyeing may follow the recognition of the role of the epicuticle in governing penetration. Removal of the epicuticle without other alteration of the fiber may overcome many difficulties; this suggests the urgent need for research on the chemistry of the epicuticle and the underlying intermediate layer with the object of discovering methods of modifying these without causing other effects.

Tests for "Damage" in Wool

A great number of tests for "damage" depending upon staining techniques have been proposed [20]. Most of these seem to depend upon the fact that the staining compound can gain entrance to the fiber only where the epicuticle is removed or perforated. The intact membrane does not stain and appears capable of preventing the penetration of quite small molecules. The test proposed by Whewell and Woods [25] may be mentioned as an example, particularly since the authors were led, because of the manner in which the dye entered the fiber, to say that it appeared as though "there had been damage to a superficial skin which covered the scales." The explanation of the Whewell-Woods test may be

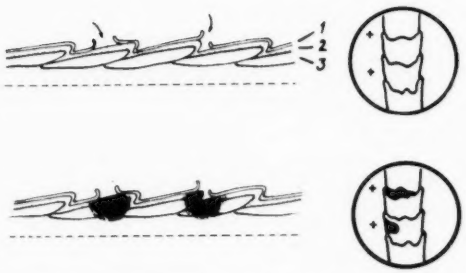

FIG. 4. *The penetration is shown of dye molecules, etc., into the fiber proper through perforations in the epicuticle. The figures at the right show the appearance of the fiber in the optical microscope. The diagram also serves to illustrate the action of many "tests for damage."*

seen from Figure 4. Pauly's test, in which diazotized sulfanilic acid is supposed to couple with phenolic groups exposed by the damage [20], is another well-known test which may be easily explained in terms of the epicuticle. The inert epicuticle will not react with the reagent, but, if abrasion or chemical alteration allows the reagent to penetrate to the protein layers beneath, the reaction may occur.

All of these tests are really tests for damage to the epicuticle and not necessarily "damage" in the textile sense. In fact, the removal of the epicuticle, leading to a strong positive test for "damage," may produce a usefully modified fiber—*e.g.*, a brief treatment with alcoholic caustic potash will lead to an easily wetted fiber, even and simple dyeing, under some conditions unshrinkability, and, owing to a higher average coefficient of friction, stronger yarns and fabrics and greater ease in spinning, *etc.* Some of these properties of treated wools have been noted [23], and here we wish merely to point out that the changes are easily explained as being a result of the removal of the protecting membrane.

Allwörden's Reaction

An analysis of this well-known reaction [1, 4] has recently been given [12]. Briefly, the cause of the blistering of the fiber surface when immersed in chlorine water is the attack of the chlorine on the intermediate layer—the exocuticle—beneath the epicuticle. The osmotic pressure arising from the solution of the decomposition products causes water to pass through the epicuticle which, acting as a

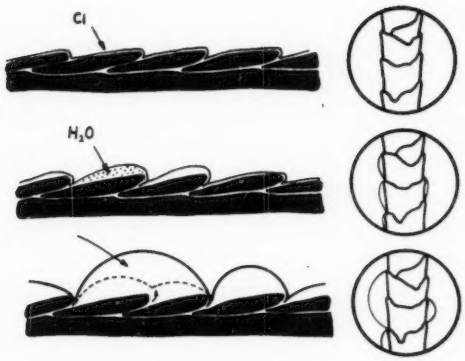

Fig. 5. *The Allwörden reaction. Chlorine penetrates the intact epicuticle, attacking the underlying layers. Osmotic swelling leads to the formation of blisters. The figures at the right show the appearance of the fiber in the microscope. The loosened epicuticle may be obtained free from the fiber by shaking.*

semipermeable membrane, is inflated, leading to the appearance of the familiar blisters. (See Figure 5.) The simplest method of preparing the epicuticle for the electron microscope—shaking lightly chlorinated wool in water—makes use of the loosening effect on the epicuticle following the action of chlorine on the cement. Again, the Allwörden reaction is of little value as a test for damage for the reasons mentioned earlier.

Shrinkproofing Treatments and Friction

It is well established that modifications of the frictional properties of wool fibers may lead to a reduction in the rate of felting [25]. This is usually attributed to a reduction in the difference in friction, μ_2–μ_1, which is the "driving force" of fiber migration. Certain other treatments—*e.g.*, with alcoholic caustic potash—do not seem to act in this way, although the frictional properties are altered. The scale resistance is not reduced significantly, but there is a rise in the average coefficient, owing to a rise in both coefficients [11]. This change, associated with the impairment of the epicuticle, apparently increases the frictional *hindrance* to fiber movement sufficiently to affect the rate of felting.

With the recognition of the several frictional factors influencing felting and the complex character of the fiber surface, a more rational attack on this problem becomes possible. The necessity for a fuller knowledge of the chemistry of the epicuticle and of the underlying cement is again obvious.

Nomenclature

Since this new knowledge of the histology of the keratin fibers will be increasingly helpful in explaining the reactions of fibers, a definite nomenclature for the new structures is therefore most desirable, and we propose consideration of the terms used here, which are based on the usage in connection with other cuticles—*viz.*, the *epicuticle*, *exocuticle*, and *endocuticle* for the components previously included in the term "cuticle"; and *fibrils*, *microfibrils*, and *cortical cement* for the components of the cortex.

Summary

An account is given of the fine histology of wool fibers and hairs as revealed by recent optical and electron microscopy. Explanations of several fiber reactions in terms of the complex structure of the cuticle are suggested. The need for a definite terminology for the new components is emphasized and some suggestions are made.

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The "Subcutis"* and Other Cuticular Preparations from Wool and Hair

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AS A RESULT of an optical examination of damaged wool fibers stained by various techniques, Reumuth [12] concluded that two sheath-like layers enveloped the cortex. He interpreted this to mean that underneath the cuticle proper there was a second layer, which was therefore named the "subcutis." Subsequently, Lehmann [7, 8] and Elöd and Zahn [2] discovered methods whereby it was possible, through the solution of scales and cortex, to isolate from wool and hair thin tubular residues, which they described as the "subcutis."

The possibility that there is an unrecognized histological component beneath the cuticle in hair is a matter of some importance, particularly as Lehmann [8] considered that it would influence markedly the dyeing properties and strength of fibers. We have therefore examined the evidence for the existence of a subcutis, and have repeated and extended the experiments of the German workers. We have confirmed their experimental findings and have obtained further evidence of the complexity of the structures enveloping the cortex of the fiber. We wish to emphasize, however, that this evidence does not necessarily demonstrate the existence of a new sheath *beneath* the cuticle, but that it may be interpreted in terms of the complex structure of the cuticle itself, which consists of at least three components [10]. In this paper we shall first of all make some brief comments on the work of Reumuth and Lehmann and shall then discuss our own experiments concerning the structure of the subcutis and other similar preparations.

Reumuth's Microscopic Evidence for the Existence of a Subcutis

Reumuth carried out an optical microscopic study of damaged wool fibers stained by such techniques

* Zahn now prefers to use the term "subepidermicula" or "Zwischenmembran."

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as Pauly's and Siebers' [12]. The interpretation of details on the verge of resolution in the microscope is always difficult, but in his micrographs it is often possible to see that there are two layers, differing in staining properties, surrounding the fiber. However, there is no particular reason given for his deciding that the external layer is the "true" cuticle and that the second layer is another component—the subcutis. Although this work was carried out with the optical microscope, which is not capable of revealing definitely the nature of the enveloping layers, it does provide evidence, in addition to that obtained by electron microscopy, of the complexity of the extracorticular structures of the fibers.

Methods of Isolating the Alleged "Subcutis"

The experiments of Lehmann [7] and of Elöd and Zahn [2] are of a different character from those of Reumuth, since they lead to the isolation from the fiber of material which amounts to approximately 5% (by weight) of the fiber and is suitable for chemical analysis or examination by microscopy and x-rays. The problem is to determine, beyond doubt, the origin of the isolated material.

Lehmann [7] heated hair and wool fibers in formaldehyde solution at 130°C for several hours. The product consisted of colorless tubes of about the same dimensions as those of the fibers. We have prepared precisely similar material and checked the optical, electro-optical, and x-ray findings. Lehmann does not give a conclusive argument to show that the tubes came from beneath the cuticle. Elöd and Zahn [2] first heated fibers at 130°C in formamide or phenol [14] and then digested them in pancreatin to obtain similar tubes. We shall refer to them as "Lehmann tubes" so as to avoid use of the term "subcutis."

On examining Lehmann tubes optically, the first thing which strikes one is that they appear to possess the same external contour as that of the original fiber. Scale edges may readily be seen, for example, in Lehmann's micrographs [7]. This observation, together with the recent discovery of the resistant epicuticle [9], which is known to be located on the fiber surface, and the knowledge that other layers exist in the cuticle [11, 12] (Figure 4), immediately suggested that the Lehmann tube may have originated from the external layers of the cuticle and that it consists, in fact, of the epicuticle thickened by a greater or lesser adhesion of the intermediate and other layers of the cuticle. Experiments were therefore carried out to check this possibility. First, we tried to separate the epicuticle from Lehmann tubes by means of the preparative technique used to separate this structure from the original fiber. Secondly, we considered whether or not a thickening of the epicuticle, caused by the adhesion of the intermediate layer after a short treatment with formalin, could be detected.

Separation of Epicuticle from Lehmann Tubes

Lehmann tubes were obtained by heating human hair for 3 hours at 130°C in 30% formalin. They appeared to be identical with those found by Lehmann. The epicuticle is usually separated from normal hair by chlorination and shaking in water, and the same technique of chlorination (5 minutes, 0.01–0.1% chlorine, 20°C) was adopted for the treatment of the Lehmann tubes on the assumption that the epicuticle would still be the most resistant component. On electron-microscopical examination of the suspension obtained from chlorinated Lehmann tubes, thin membranes (Figure 2) typical of the epicuticle were obtained. Figure 2 may be compared with Figure 1, which shows the epicuticle from normal wool. The difference in appearance in transmission is probably due to the incomplete removal of the hardened protein from the epicuticle by the chlorine in the case of the Lehmann tube. The same characteristic folding of the thin layers was to be seen. There is, thus, little doubt that the Lehmann tube does contain a thin chlorine-resisting membrane similar to the epicuticle, which we know to be located on the outside of the fiber. The possibility remains that there may be two such resistant membranes, the second one being beneath the cuticle. There is, however, no other evidence as yet of a second membrane of this nature.

Epicuticle from Partly Formalized Wool

The epicuticle was also separated from wool fibers which had been only lightly treated with formalin (10 minutes, 40% formalin, 100°C). In this case (see Figure 3) the incipient adhesion of material to the epicuticle can readily be seen. Thicker deposition in this manner by heating further would produce a tube of the same thickness as Lehmann tubes.

Thus there is evidence that the Lehmann tube does originate from the outside of the fiber and that it consists (see Figure 4) of the epicuticle, *1*, thick-

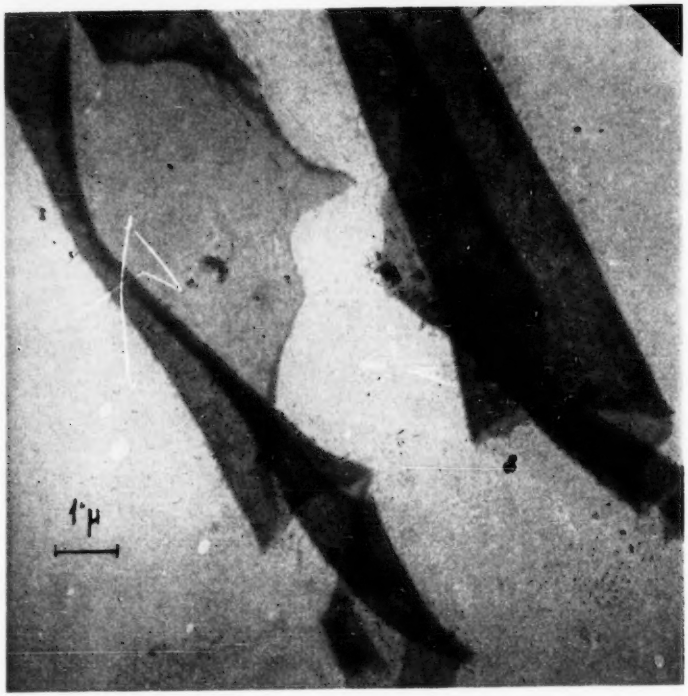

FIG. 1. *Electron micrograph of epicuticle obtained from wool fibers by light chlorination. Note thinness and tendency to fall into folds.*

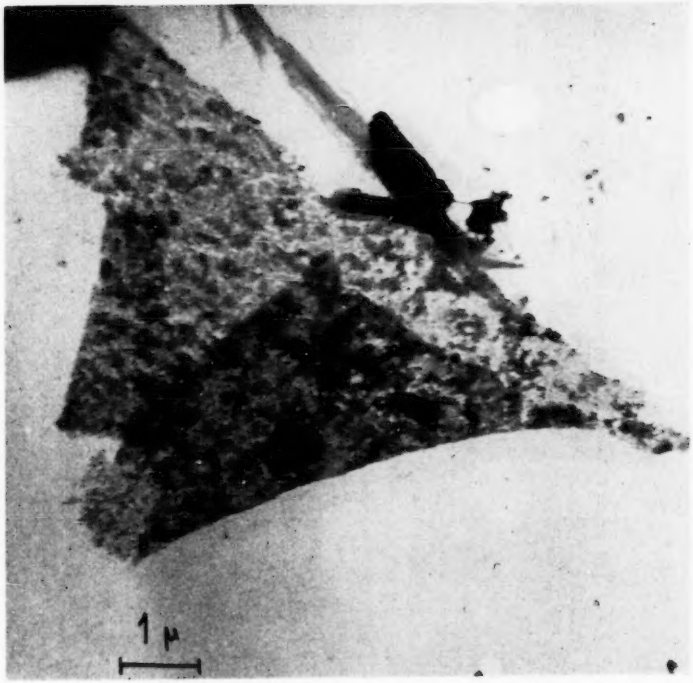

FIG. 2. *Resistant membrane (presumably epicuticle) obtained from Lehmann tubes. The difference in appearance from membranes of Figure 1 seems to be due to adhering protein. The same tendency to fold may be observed.*

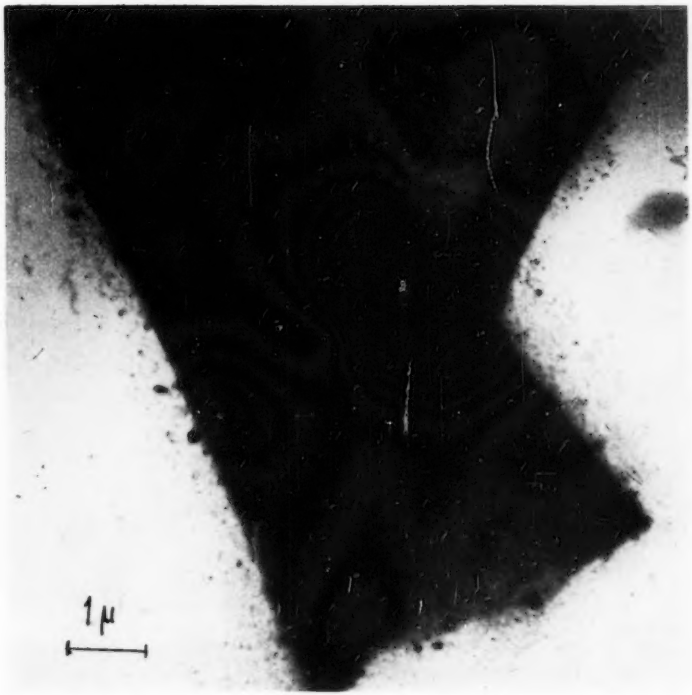

FIG. 3. *Epicuticle from wool lightly treated with formalin. The thickening due to adhering protein may be seen (cf. Figures 1 and 2).*

ened by a greater or lesser deposition of the exocuticle, *2*, and perhaps also the endocuticle, *3*. Figure 4 shows diagrammatically the complex structure of the cuticle as revealed mainly by the electron microscope, and the manner in which the two external layers, *1* and *2*, may combine to yield a tube is shown at *S*. The intermediate layer, *2*, appears to be a protein which differs from the rest of the fiber keratin, because on heating with formaldehyde it hardens and becomes firmly attached to the epicuticle, whereas the rest of the fiber dissolves.

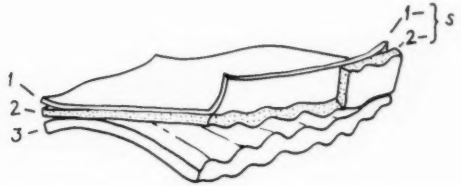

FIG. 4. *Drawing to illustrate the relative positions of the several components of the cuticle:* (1) *the external epicuticle,* (2) *the exocuticle, and* (3) *the endocuticle. Layers* 1 *and* 2 *may unite to form a tube as suggested at* S.

Tubes Obtained by Tryptic Digestion of Supercontracted Fibers

Tubular forms, again described by Elöd and Zahn as "subcutis," are obtained by the tryptic digestion of fibers which have been supercontracted by heating in formamide or phenol [2, 14]. For our purposes, wool fibers were heated in phenol at 100°C for 2 hours, washed, and digested for 24 hours in trypsin at pH 8-9. The thin, colorless tubes showed scale markings very clearly. In the electron microscope they were found to be much thinner than Lehmann tubes and making transmission micrographs was possible. The "scale edges" showed up clearly as folds in the thin sheets. The appearance was similar to that of the external surface of the fibers, as revealed by the replica technique. There was little doubt that these tubes were similarly composed of epicuticle and exocuticle.

FIG. 5. *Electron micrograph of a portion of a "Geiger sheath" showing the thickened portion and the thinner epicuticle lightly covered with adhering exocuticle. (Gold shadowed.)*

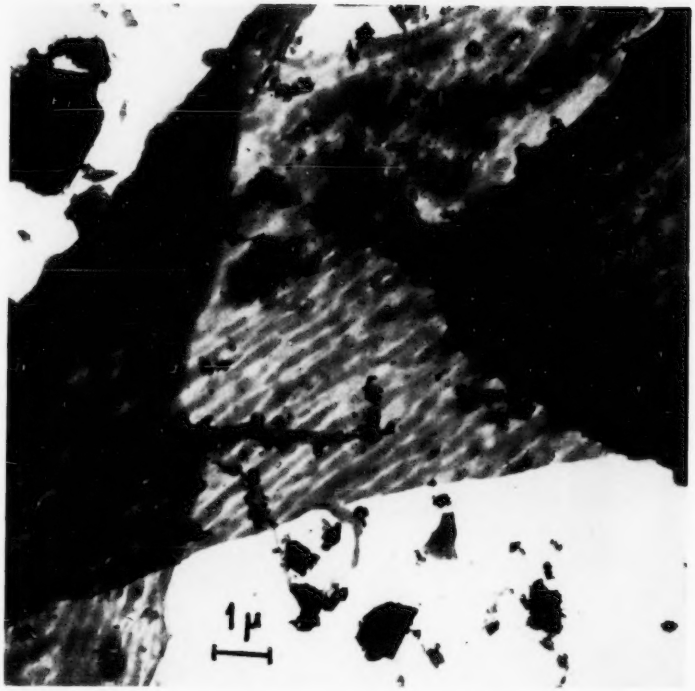

FIG. 6. *Portion of typical Geiger sheath. The ridges running parallel to the fiber direction may be seen (cf. Figure 8). (Transmission electron micrograph.)*

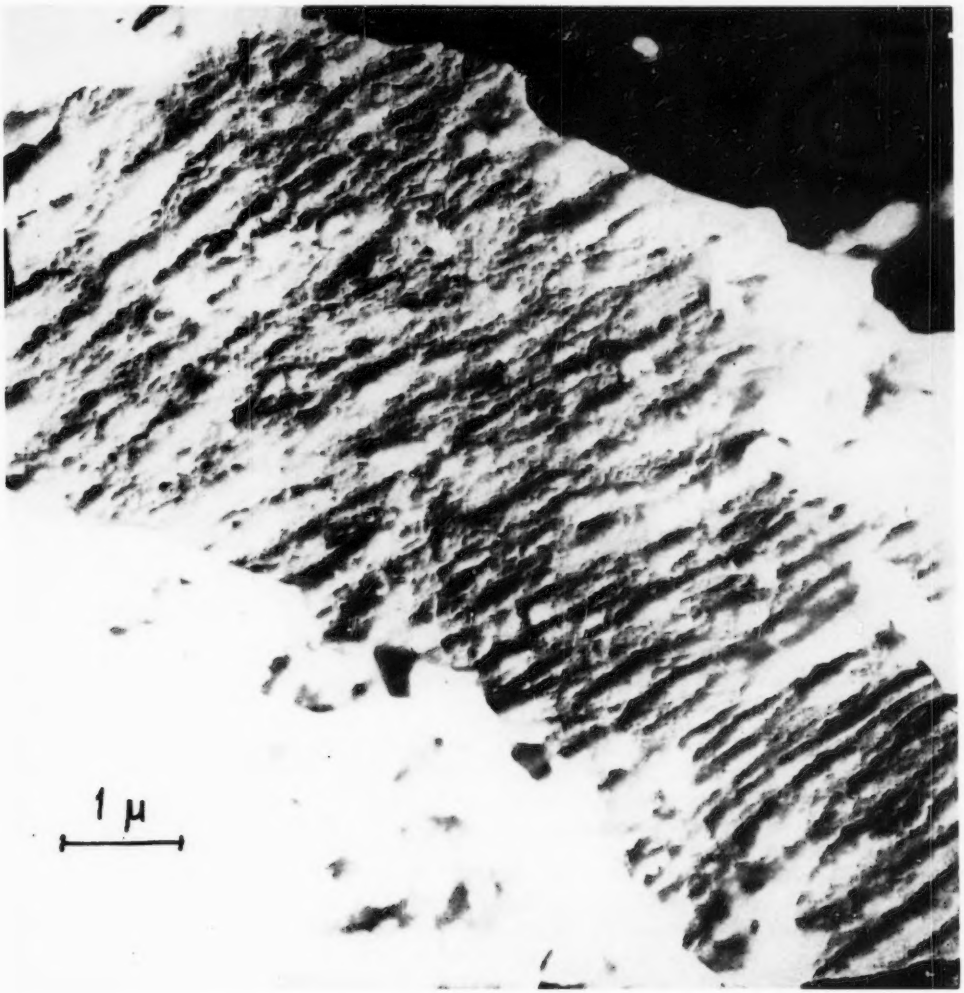

FIG. 7. *Portion of typical Geiger sheath. (Gold shadowed.)*

Geiger Sheaths

The conclusions reached by the present authors concerning the structure of Lehmann tubes were made more probable through the study of similar tubular forms obtained from fibers by other means, but not described by their discoverers as "subcutis" [4].

In electron micrographs of cuticular material obtained from wool, two types of material have been described as "scales": (*a*) the uneven pock-holed flakes obtained by tryptic digestion (see figures in Mercer and Rees [11] and Gorter and Houwink [5], and Figure 8 of this paper) and (*b*) extensive flat sheets crossed by ridges resembling scale edges obtained by the peptic digestion of reduced and ethylated wool (see Elöd and Zahn [3, 13] and Hock and McMurdie [6]). This latter material, obtained in the form of tubes and remnants by the complete

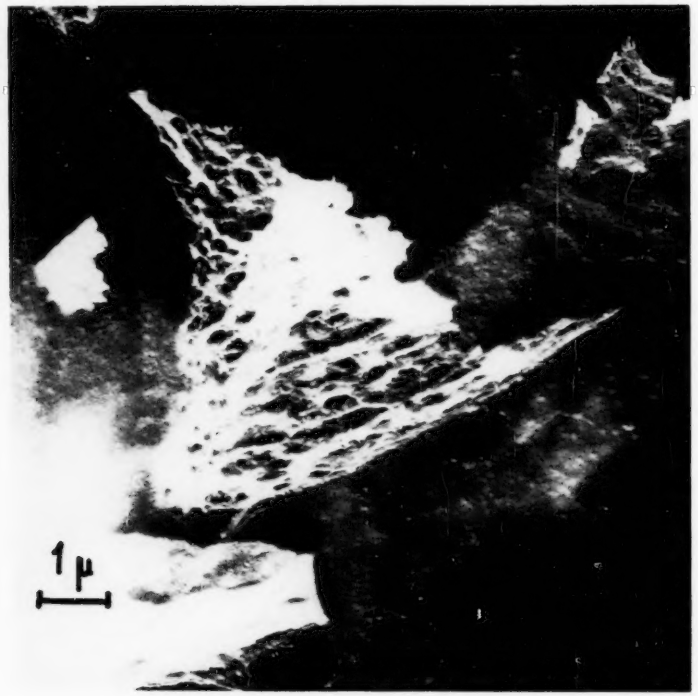

FIG. 8. *Fragment of the endocuticle (most resistant component) obtained from overchlorinated wool. Sheets of the epicuticle may also be seen, but the exocuticle (least resistant component) has been etched away. (Gold shadowed.)*

removal of the cortex, has been analyzed by Geiger [4]. We shall refer to it as "Geiger sheaths." Superficially, these tubes resemble closely the Lehmann tubes and show clearly the scale marks of the original fibers [4].

For electron-microscopic examination this material was obtained by ethylating wool in a one-stage reduction and ethylation process adapted from that described by Brown and Harris [1]. The ethylated wool was digested in 0.05% pepsin at 35 C and pH 1.5. The sheaths were obtained more or less free from cortex in about one week. Electron-microscopic examination clearly revealed that they also consisted of the epicuticle thickened by adhering material. They were less uniformly thick than Lehmann tubes and in places, as may be seen at "EPIC" in Figure 5, the epicuticle alone was visible; in other sheaths the adhering material occurs in patches (see Figure 6). In Figure 7, which is an electron micrograph of gold-shadowed material, the gradation in thickness is readily seen. When fully thickened, the Geiger sheath shows: (*a*) ridges* running across the sheaths roughly at right angles to the fiber direction, consisting of a greater thickness of material deposited where the epicuticle is carried over a scale edge (see Figure 6); and (*b*) smaller ridges running along the fiber. These may be imprints of the ridges to be seen on the endocuticle (see Figure 4 for terminology) obtained in tryptic digests.

Histologically speaking, the two tubes are very similar, but during isolation they may have been chemically modified in different ways. The Lehmann tube seems to owe its origin to the fact that the intermediate layer becomes hardened and insoluble in the formalin treatment. The Geiger sheath is less uniform in thickness and appears to result partly from the relative indigestibility of the protein of the intermediate layer in pepsin and partly also from the protection against enzymic at-

* These ridges give to the complete sheath the appearance of scale edges when viewed optically.

tack afforded from one side by the adhering epicuticle.

Conclusions and Summary

Three components may be recognized in the cuticle of wool and hair: endocuticle, exocuticle, and epicuticle [10]. The epicuticle, although exceedingly thin (100 A.), is very resistant chemically; the intermediate layer, although protein in character, also differs considerably from the keratin of the cortex and the endocuticle. It is therefore possible, by dissolving the keratin, to separate the epicuticle, thickened by the adhesion of more or less of the intermediate layer, in the form of a continuous tube, the external surface of which is that of the original fiber.

A method of preparing such tubes by heating fibers in formalin was described by Lehmann, but the material was thought to originate beneath the cuticle and was named the "subcutis." Histologically, similar tubes result from the tryptic digestion of supercontracted fibers and the peptic digestion of reduced and ethylated wool, as described by Geiger.

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X-Ray Microradiography of Fibers and Fabrics*

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Abstract

Soft x-rays or Grenz rays can be used to form shadowgrams of single textile fibers as well as of yarns and fabrics on fine-grain photographic plates. This paper deals primarily with the microradiography of single fibers and includes a description of experimental equipment, conditions under which necessary resolution is obtained, impregnation of fibers with substances to increase absorption of x-radiation, and examples of the utility of the method. Single cotton, rayon, wool, and other fibers are clearly resolved by x-radiation generated at 5 kv.; at higher voltages (to 17 kv.), natural fibers give faint shadowgrams. When the fibers are impregnated with 10–20% lead sulfide or other materials, single treated fibers can then be distinguished in masses of untreated fibers. This technique provides a possible means for tracing individual fibers through processing operations.

X-RAYS of comparatively long wave length—up to 3 A.—can be used to form shadowgrams of textile fibers, yarns, and fabrics on photographic plates. When a fine-grain emulsion is used, the images contain considerable detail which is revealed by photographic enlargement or photomicrography. The use of radiography in several fields has been described recently by Sherwood [8–11], by Clark and Gross [1], and by Maddigan [5, 6], but little application has been made to textile processing. Suitable commercial x-ray equipment is available, and the method appears feasible for studies of processing operations, analysis of textile structures such as weave, twist, etc., and examination of certain types of finishes. This paper is a description of methods developed primarily for the microradiography of single fibers, and includes a description of equipment, conditions under which necessary photographic resolution is obtainable, and impregnation of fibers with absorbing substances, with an indication of possible utility.

The method of microradiography is to be distinguished from the familiar techniques of photomicrography and x-ray diffraction in several important respects. The image obtained is a shadowgram, of essentially the same size as the original, but with such detail that it can be enlarged by photographic means more than 100 times. It is analogous in some respects to the microphotographic techniques in which a very small image of a large object is formed. Photomicrography, on the other hand, is used to obtain a large image of a very small object. X-ray diffraction is entirely different, since penetrating monochromatic radiation is employed to obtain a diffraction pattern of molecular structure, and the resulting photograph is not an image, in the sense of direct delineation of form, of the original object. Mention may be made also of the method described by Trillat [12], in which hard x-rays are used to liberate secondary photo-electrons either directly from the object under study or from a metallic surface in close contact with the object; the photographic image is formed by these photoelectrons.

Substances of comparatively low density such as those used as textile materials are, of course, easily penetrated by radiation of the wave lengths commonly associated with x-rays. In order to produce a shadow image of fibers on a photographic plate, it is necessary to use radiation of low penetrating power, generated by voltages from 3 to 15 kilovolts (kv.), approximately, for such "soft" x-rays, or Grenz rays, are absorbed in part by fibers. For the purposes of this work, resolution of the entire fiber only was sought; resolution of the fine structure within the fiber is difficult, if not impossible, to obtain by the procedure used.

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X-Ray Equipment and Performance

Some preliminary tests were made with a portable x-ray unit (General Electric Co., Model F-2). This instrument operated at about 45 kv. and the radiation was too penetrating to photograph single fibers. In order to obtain less penetrating radiation, the primary voltage of the tube transformer was reduced with a Variac. For 25–30 v., primary, it was estimated that the secondary voltage was 12–15 kv. No satisfactory images could be obtained at such voltages, however, probably because the tube window was too thick to permit the soft x-radiation generated to pass. A photograph of yarns taken with the tube operating at full voltage is shown in Figure 11. A further disadvantage of this unit for research purposes lies in the fact that the rectifier gave only half-wave rectification—during half the operating time no radiation was being generated, and during the other half of the cycle the voltage changed from zero to a maximum and back to zero again. The radiation was therefore intermittent and very inhomogeneous.

A Machlett x-ray tube, Type AEG-50, with a thin beryllium window (1.0 mm.) to permit passage of soft x-rays (*i.e.*, rays of comparatively long wave length), was obtained. The water-cooled anode is of vacuum-cast copper with a tungsten target [4, 7]. The focal spot is 1.5 mm. square in projection, with a coverage of 40° solid angle, giving a beam of about 20 cm. in diameter at a distance of 25 cm. from the window. The tube was mounted on a bracket which allowed it to be raised or lowered; a pointer and scale showed the distance between the window and the base on which the photographic plate was placed for exposure.

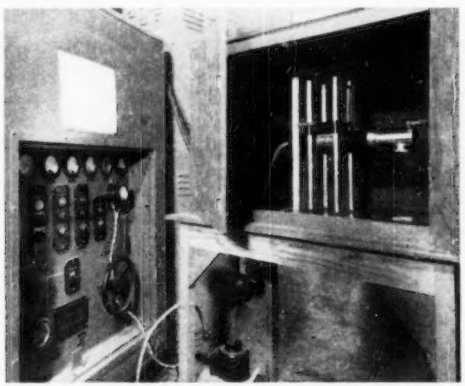

FIG. 1. *General view of apparatus. (X-ray tube at right, control panel of rectifier unit at left.)*

A satisfactory source of direct current for the Machlett tube was obtained from a surplus Army radar rectified unit, Type RA-38. This unit gives full-wave rectification, with a ripple in direct current of less than 0.5%. The maximum output of the unit is 0.5 ampere at 15 kv. or 7.5 kilowatts, which is far above the requirements of the x-ray tube. The high-voltage leads were reversed in polarity so that the anode of the x-ray tube could be grounded. A filament transformer for 15 kv. was used to supply the filament current for the tube; by varying the input voltage of this transformer the filament current could be controlled. Actual current through the x-ray filament was initially determined by connecting an ammeter in the circuit and plotting a graph of filament current *vs.* input voltage. In all subsequent experiments, the filament current could be read from this graph by observing the input voltage on a voltmeter in the primary circuit. Meters in the rectifier unit permitted direct reading of the high voltage across the x-ray tube and the current through the tube. The arrangement of the apparatus is shown in Figure 1.

Nature and Distribution of Radiation from X-Ray Tube

The radiation emitted from an x-ray tube consists of a continuous spectrum of all wave lengths down to a minimum wave length, λ_0, determined by the voltage, V_0, across the tube. Superimposed on this continuous spectrum there may be characteristic radiation which depends upon the voltage and also upon the target material. Since, in the present work, the usual maximum voltage used is 15 kv. and the target is tungsten (with high atomic number), the characteristic radiation can be completely neglected. For the continuous spectrum, the intensity or energy distribution can be expressed as a function of either wave length or voltage by means of the formula

$$I_\lambda = KV^2(V_0 - V),$$

where I_λ is the intensity at wave length λ, K is a constant depending upon the physical characteristics of the target and upon the number of electrons striking it per second, V_0 is the voltage across the tube, and V is the voltage corresponding to λ. If V is expressed in kv. and λ in Angström units, $V = 12.345/$

λ. The maximum intensity of the beam occurs at a wave length approximately equal to $3/2\ \lambda_0$ (the minimum wave length).

It is instructive to examine the intensity distribution for several voltages (*e.g.*, 5, 10, and 15 kv.). This is calculated first for the beam as it originates at the target by means of the formula given above. Then, because different wave lengths are absorbed differently by the beryllium window and by the air between window and photographic plate, not only is the over-all intensity of the beam reduced but the shape of the distribution curve is greatly altered. These points are illustrated by the graphs in Figures 2 and 3, where relative intensity, I_λ/K, is plotted as a function of λ.

Curves I, IV, and VII show the distribution of intensities at the target for voltages of 15, 10, and 5 kv., respectively. In Figure 3, curves IV and VII of Figure 2 are redrawn to an expanded intensity scale. Two features of these curves may be pointed out: not only does the intensity at each wave length fall rapidly with decreasing voltage, but also the region of greatest intensity is shifted toward the longer wave lengths. The area under each curve may be taken as a measure of the total amount of x-radiation leaving the target. By means of a planimeter, these areas (up to 12.0 Å.) were found to be in the ratio of 20.6:8.4:1.6.

Part of the radiation leaving the target is absorbed by passage through the tube window and the air. The reduction in intensity is given by the familiar absorption formula

$$I = I_0 e^{-\mu d},$$

where I is the intensity of a beam I_0 after passage through a layer of absorbing material of thickness d, μ being the linear absorption coefficient of the material. Since μ varies with wave length, the reduction in intensity cannot be calculated for the whole beam but must be found for each wave length in the beam. Curves II, V, and VIII (Figures 2 and 3) show how curves I, IV, and VII, respectively, are altered as the beam passes through the beryllium window of the tube. The important point to note is that virtually all radiation above 4 Å. is absorbed by 1.0 mm. of beryllium. Since the proportion of radiation below 4 Å. is much greater at 15 kv. than at 5 kv., it is apparent that the proportionate loss in total energy is much less at the higher than at the lower voltage. Data of Table I show that about 40% of the original radiation emerges

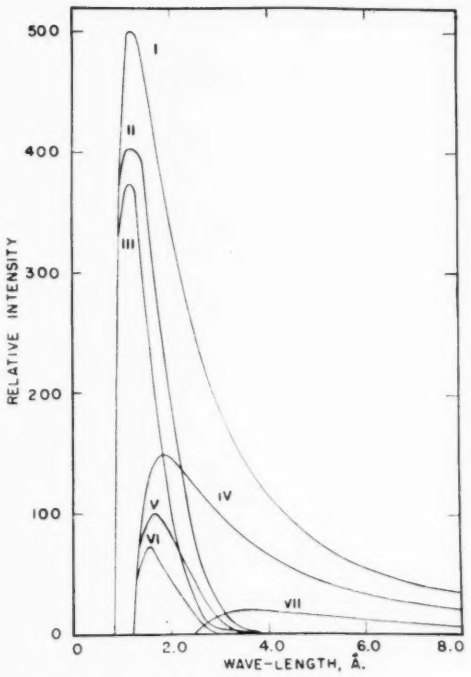

FIG. 2. *Curves showing variation of relative intensity of x-ray beams with wave length. Tube voltage, 15 kv.:* I, *at target;* II, *through beryllium window;* III, *through 25 cm. air. Tube voltage, 10 kv.:* IV, *at target;* V, *through window,* VI, *through 25 cm. air. Tube voltage, 5 kv.:* VII, *at target.*

from the tube at 15 kv., but less than 3% at 5 kv. Traversing the air-space between the window and the photographic plate causes a further loss in intensity, and again the loss is greater at the longer wave lengths. Curves III, VI, and IX show the relative intensity of the beam that finally reaches a plate placed 25 cm. from the tube window. Since most of the long wave-length radiation has already been absorbed by the window at 15 kv., the air has much less effect on the intensity than the window had, there being a further reduction of about 10%. But since there is relatively little short wave-length radiation in the 5 kv. beam, the absorption due to air is very serious, and only about 0.3% of the original beam reaches a plate 25 cm. away. Hence, while the energy of the initial beam at 15 kv. is only about 2.5 times that at 10 kv., and 13 times that at 5 kv., the corresponding factors 25 cm. from

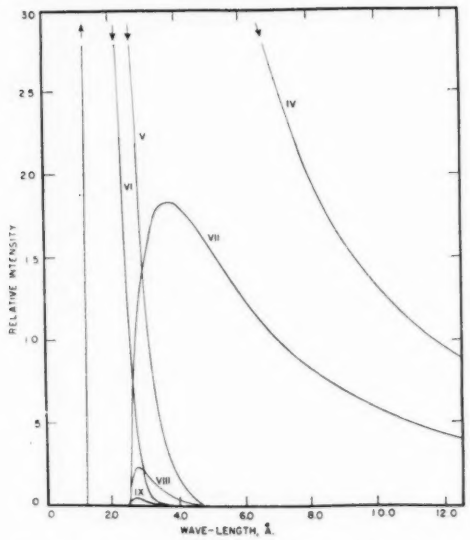

FIG. 3. *Curves showing variation of relative intensity of x-ray beams with wave length (expanded intensity scale). Tube voltage, 10 kv.:* IV, *at target;* V, *through beryllium window;* VI, *through 25 cm. air. Tube voltage, 5 kv.:* VII, *at target;* VIII, *through window;* IX, *through 25 cm. air.*

the window are 5.6 and 1400. Such considerations show why, for work at long wave lengths, it is necessary to evacuate the space between window and plate. (For a recent study of absorption of x-rays by air, see Day and Taylor [2].)

These matters have been considered at length because of their importance in understanding the possibilities and the limitations of the use of x-ray photography. Nearly all of the radiation will be below 4 A. in wave length; from this upper limit, the wave length extends to 0.9 A. for 15 kv. and to 2.5 A. for 5 kv., the practical limits of voltage for our equipment. Furthermore, since photographic emulsions can be considered to be equally sensitive to all wave lengths in this narrow band, the areas under the curves in Figures 2 and 3 afford a measure of the relative exposure times that are required. Thus, if an exposure of 10 sec. is required at 15 kv., then, other conditions being unchanged, 14,000 sec., or nearly 4 hrs., would be required at 5 kv. One also sees why the inverse-square relationship between distance and exposure time does not hold at the lower voltages. Suppose, for example, the proper exposure time at 15 kv. and 25 cm. is 100 sec. If the tube is moved down to within 10 cm. of the plate, by the inverse-square law the exposure time would be $100 \times (10/25)^2$, or 16 sec. But, as Table I shows, the relative intensity of the x-ray beam at 10 cm. is 67, compared with 56 at 25 cm. Hence the exposure would be not 16 sec. but rather $16 \times 56/67$, or 13.4 sec., a gain of 20%. At 5 kv., on the other hand, the proportional gain is much greater, because air absorbs so much more of the radiation. An exposure of 100 sec. at 25 cm. would be reduced to $16 \times 0.04/0.13$, or 5 sec., at 10 cm., a gain of over 60%.

To summarize briefly these observations on the behavior of an x-ray beam as it concerns the immediate practical problem of x-ray photography, it may be noted that: (1) intensity decreases very rapidly as voltage decreases; (2) the radiation at lower voltages is not only less intense but also less penetrating than at higher voltages; and (3) absorption of radiation by air is far more important at low voltages; hence for work in this region the tube should be brought as close to the plate as other considerations warrant. Table I may be used to form a rough estimate of relative exposure times, which vary inversely with the intensity of radiation.

Photographic Plates and Films

Since the width of many textile fibers lies between 10 and 40 microns (0.01 and 0.04 mm.), it is clear that the resolving power of the photographic emulsion used in radiography of single fibers must be great enough to show such small objects distinctly. The usual emulsion, with resolving power of 50-60 lines per mm., cannot reveal clearly images smaller than 20 μ. Furthermore, in many cases it is desirable to magnify images of fine fibers. A fine-grain emulsion is therefore required, and Eastman Type 548-O spectrographic plates are excellent for the

TABLE I. RELATIVE TOTAL RADIATION IN X-RAY BEAM AT DIFFERENT VOLTAGES

Tube voltage (kv.)	At the target	Relative total radiation After passage through Beryllium window (1.0 mm. thick)	Window and 10 cm. air	Window and 25 cm. air
5	16	0.4	0.13	0.04
10	84	18	14	10
15	206	79	67	56

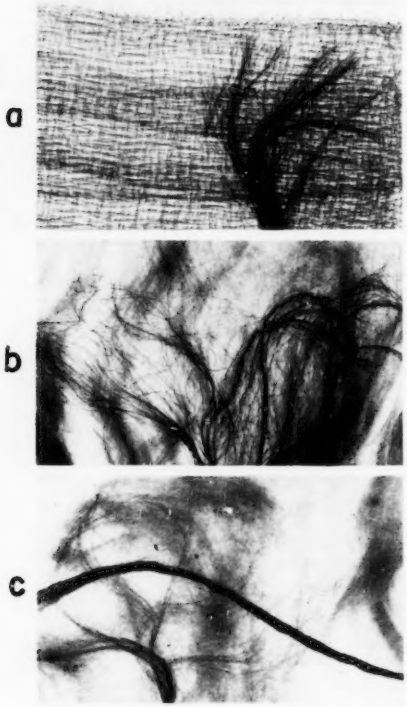

FIG. 4. *X-ray photographs of rayon filaments containing over 50% barium sulfate.* (a) *On Eastman spectrographic emulsion 548-0; 15 kv., 30 ma., 25 cm., 60-sec. exposure. Background: surgical gauze.* (b) *On Process Ortho film; 5 kv., 5 ma., 25 cm., 20-sec. exposure. Background: cotton sliver.* (c) *On Du Pont x-ray film; 5 kv., 5 ma., 25 cm., 11-sec. exposure. Background: cotton sliver.*

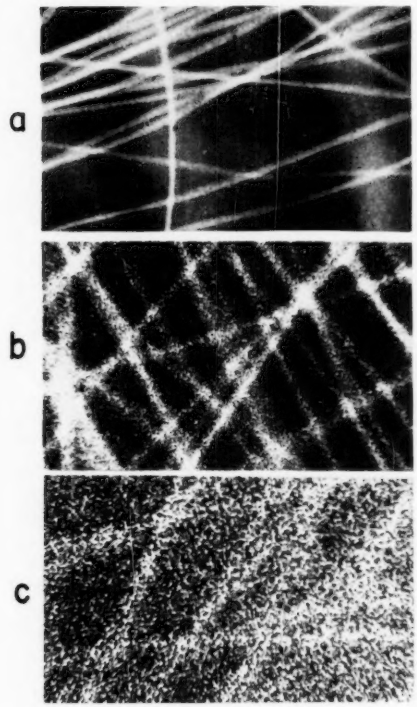

FIG. 5. *Contact prints from photomicrographs of negatives used in Figure 4* (50×): (a) *from 4a;* (b) *from 4b;* (c) *from 4c. (In these pictures, the fibers that appeared black in Figure 4 appear white because of reversal of black and white in the photomicrographic process.)*

purpose. One advantage of using them is illustrated in Figures 4 and 5. Viscose rayon fibers containing over 50% barium sulfate were photographed by x-rays on three different types of emulsion—the 548-0 plate, Eastman Contrast Process Ortho film and Du Pont Safety X-ray film. The fibers are about 25 μ in diameter, and individual fibers are distinct even on the relatively coarse-grain x-ray film. Magnification, however, exaggerates the differences. Figure 5 shows areas of each of the negatives for Figure 4 enlarged 50 times; the negative was placed on the stage of a microscope and a photomicrograph was taken in the usual way. The difference in grain size is strikingly evident: the spectrographic plates are capable of further enlargement, while almost all image has been lost from the x-ray film.

Some sacrifice has to be made to obtain the fine resolution of the 548-0 emulsion. The fine-grain plates have low sensitivity, which necessitates a greatly increased time of exposure. For any given voltage and distance between tube and plate, the intensity of the x-ray beam is directly proportional to the electron current flowing between cathode and anode. The proper exposure time is therefore inversely proportional to this current. Hence the product of electron current by exposure time (milliampere-seconds) affords a measure of film sensitivity at the given voltage and distance. In Table II sensitivities expressed in this way, as determined

experimentally, are given for the three emulsions used. The general rule that fine grain and high resolution are accompanied by low speed is illustrated.

The extreme slowness of the 548–0 spectrographic plates is a very definite advantage in most cases. The plates are slower than the old printing-out papers and can be handled and developed in dim, diffuse daylight without fogging, although a red or yellow safelight in a fairly dark room is usually used. It is possible, therefore, to place the plate properly under the x-ray tube, arrange the samples on it, make the exposure, and develop the plate under convenient lighting conditions. With the other emulsions, the usual precautions had to be taken to darken the room adequately, or else the film had to be kept in a lightproof holder and covered with a suitable filter (*e.g.*, Wratten No. 87) during exposure. Both alternatives were inconvenient and, in the second case, there was always the possibility that the filter might absorb some of the x-radiation along with the visible light. When voltages near 5 kv. are used, exposures are so greatly prolonged with the spectrographic plates that the inconvenience of using the faster emulsions is largely compensated for. At voltages of 8 kv. or higher, the exposure time for the 548–0 plates is not excessive: at 15 kv. and 30 milliamperes (ma.), 1 min. is usually adequate. Accordingly, these plates were used for most of the pictures taken in the work described. To avoid staining during development, the manufacturer's recommendations were followed. Except where noted to the contrary, Eastman developer D–19 (5 min. at 68°F) was used to give maximum contrast, followed by washing in water for 3 min. The plates were fixed in fresh hypo for 5–10 min., and the hypo was changed frequently.

FIG. 6. *X-ray photograph of cotton sliver wound with cotton roving and copper wire (15 kv., 30 ma., 25 cm., 45-sec. exposure).*

The experimental procedure used in making the x-ray photographs follows. The plate is placed directly under the window of the x-ray tube, and the specimen is laid on the plate. (Lead numbers, like those used for x-ray work in hospitals, are stuck to a bit of Scotch tape and placed in one corner of the plate for identification.) Since the x-ray beam is divergent and inevitably there is some scattering of light by the fibers, the conditions for obtaining a sharp image must be determined. According to the manufacturer of the x-ray tube, if the distance between window and object is at least 20 times that between object and plate, the outlines of the images will be sharp. Our experience has borne out this claim. Very fine wires (Wollaston wires, 5 μ in diameter), raised 1 cm. above the plate, gave sharp images when the tube was 25 cm. above. Figure 6 also illustrates the point: it shows a loop of cotton sliver 1–2 cm. thick, around which was wound loosely a length of cotton roving and a fine copper wire. The wire at some points was 2 cm. above the plate, yet the image is uniformly sharp. When such photographs are considerably magnified—30 times or more—then the fuzziness at the boundaries becomes serious. But since, in practice, no such magnifications are necessary for the purposes in mind, and since the objects to be studied will in general be less than 2 cm. from the plate, no difficulty is anticipated from lack of good definition.

TABLE II. RELATIVE SENSITIVITY OF THREE EMULSIONS TO X-RAYS (DATA OBTAINED WITH TUBE WINDOW 25 CM. FROM FILM; OPERATING VOLTAGE 5 KV.)

Emulsion	Sensitivity (milliampere-seconds)
Du Pont Safety X-ray	50
Eastman Process Ortho	300
Eastman Spectrographic Type 548–0	70,000

In order to take the pictures, the fibers were mounted in brass holders 1¾ × 2¼ × ⅛ in. with an opening 1 × 1½ in. (see Figure 7). A recess about 3/16 in. wide was machined about the opening, the thickness being reduced to about 1/32 in. (0.8 mm.), and on this recess the fibers were mounted by means of a cellulose nitrate lacquer. The holders were then arranged on the photographic plate below the window of the x-ray tube. Thus the fibers were brought to within 1 mm. of the plate; yarns were raised above this height by their own thickness.

Visual examination of the plates is most effectively made by means of a binocular (wide-field) microscope. Low-power photomicrographs of selected areas of the plate are useful for record purposes. Alternatively, straight photographic enlargements can be made. Reproduction of the photographs by the half-tone process results in an appreciable loss in clarity.

Impregnation of Fibers

One of the objectives in undertaking this investigation was to develop a method of following individual fibers through one or several textile processes. To do this it was necessary to mark certain fibers in order that they might be distinguished later on from the bulk of the material. Fibers impregnated with metals or metal salts are more absorbent of x-rays than untreated ones. To the extent to which such treatment was successful, the treated fibers would appear lighter than untreated ones on the plate.

As was noted above, the untreated fibers themselves were found to be absorbent, so that it became necessary to find a means of increasing the absorbency by impregnation until there was sufficient contrast between the treated and untreated material to make the former distinguishable. At the same time it was desirable to change the other properties (*e.g.*, tensile strength and surface friction) as little as possible.

In the first attempts to render cotton fibers more absorbent to x-rays, silver was deposited within the fibers. This metal was chosen, in spite of its rather low atomic number (47), because of the readiness with which its salts are reduced in alkaline medium to the metallic state after it has been put into the fiber. Cotton was soaked for varying lengths of time in 5% or 10% solution of silver nitrate; a small amount (0.05%) of the wetting agent, Aerosol-OT, was added to the solution to facilitate penetration.

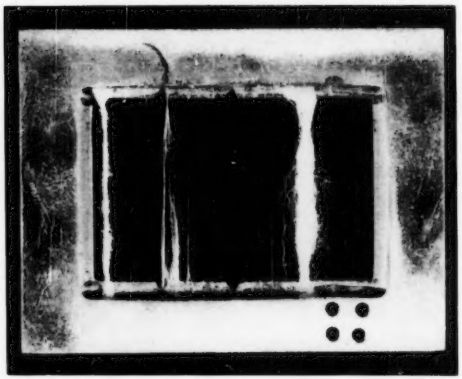

FIG. 7. *Fiber holder.*

After excess solution had been squeezed out, the sample was immersed in a photographic developing solution (Eastman D-72) to reduce the silver nitrate to metallic silver. The silver content was determined by analysis. A single treatment in 5% silver nitrate introduced about 5% silver into the fibers; the amount could be increased by repetition of the impregnating process. Examination of thin cross sections under the microscope showed that silver was in both the lumen and the cell wall.

When 10% silver was present in the fibers, they could be distinguished from untreated ones on the photographic plate after exposure, but the difference was hardly great enough to permit finding comparatively few marked fibers in a mass of unmarked ones. While further study of the several variables involved, such as exposure times, might make this method of impregnating with silver effective, attention was turned to lead, a metal with greater absorptive power for x-rays. Lead cannot be easily reduced, however, without damaging the cotton fibers. Since it was considered important for the impregnating material to be in an insoluble form, the fibers, soaked in a solution of lead acetate, were hung in an atmosphere containing hydrogen sulfide to convert the acetate to insoluble sulfide. Acetic acid liberated in the process might, under some conditions, weaken the fibers. By diluting the hydrogen sulfide with air and by keeping the mixture continuously streaming around the sample, most of the acid was evaporated as fast as it formed. In order to detect any loss in tensile strength during impregnation, the Pressley strength index was measured on each sample.

TABLE III. VARIATION IN LEAD CONTENT AND TENSILE STRENGTH OF FIBERS WITH CONCENTRATION OF LEAD ACETATE AND HYDROGEN SULFIDE (SAMPLES SOAKED 30 MIN. IN LEAD ACETATE AND EXPOSED 90 MIN. TO GAS)

Concentration of lead acetate (%)	Concentration of hydrogen sulfide in air					
	10%		25%		50%	
	Lead (%)	PSI*	Lead (%)	PSI*	Lead (%)	PSI*
10	4.9	6.3	5.0	7.2	5.2	7.2
20	7.3	5.1	6.3	7.2	8.7	7.3
40	8.8	6.1	14.3	6.9	19.2	5.9

* Pressley strength index.

Except for a few preliminary tests with absorbent cotton, the fibers used were 1⅛-in. staple cotton in the form of combed sliver. The general procedure for impregnation was as follows. To lead acetate solutions containing 0.5–1.0% Triton X–100 as wetting agent, just enough acetic acid was added to clarify the slight turbidity. The pH of these solutions, measured with a Beckman pH meter, was 4.5 at 10%, 4.3 at 20%, and 3.8 at 40% lead acetate. After soaking in the solution, the cotton samples were squeezed as nearly dry as possible and hung in 1-liter filter flasks through which the air-hydrogen-sulfide mixture flowed. Several flasks were arranged in tandem so that a number of samples could be treated at the same time. Hydrogen sulfide was obtained from a commercial cylinder of the gas and bubbled through a Fisher-Milligen gas-washing bottle. Air from the compressed-air line was likewise washed, and the two gas streams were combined before entering the train of flasks. The wash-bottles not only served to scrub the gas and air, but also saturated them with water vapor so that the samples in the flasks would not dry out. The ratio of hydrogen sulfide to air was estimated with sufficient accuracy by counting bubbles in the wash bottles. After the sulfide treatment, the samples were thoroughly washed in running water to remove any acetic acid and unreacted lead acetate. During washing, lead sulfide adhering loosely to the fibers was also removed. The samples were then oven-dried at 100–110°C. The lead content of the dried samples was determined by analysis.

TABLE IV. VARIATION OF TENSILE STRENGTH WITH EXPOSURE TO HYDROGEN SULFIDE (SINGLE IMPREGNATIONS IN 10% LEAD ACETATE)

Time in hydrogen sulfide (hrs.)	Lead content (%)	Pressley strength index
0 (control)	0	7.5
¼	4.7	7.5
½	5.5	7.4
1	5.2	7.4
2	4.5	7.2
4	4.6	6.6

TABLE V. VARIATION IN LEAD CONTENT AND TENSILE STRENGTH OF FIBERS WITH REPEATED IMPREGNATIONS (SAMPLES SOAKED IN 20% LEAD ACETATE AND EXPOSED TO 10% HYDROGEN SULFIDE FOR ½ HR. FOR EACH IMPREGNATION)

Number of impregnations	Total time in hydrogen sulfide (hrs.)	Lead content (%)	Pressley strength index
0 (control)	0	0	7.5
1	½	6.7	7.5
2	1	8.6	7.0
3	1½	11.8	6.7
4	2	14.2	6.7
5	18	24.9	4.8

The effect of the following variables was studied in an effort to increase the total amount of lead retained, to increase the amount of lead inside the fiber wall and lumen, and to minimize loss in tensile strength: (1) concentration and temperature of the lead acetate solution; (2) concentration of and time exposed to hydrogen sulfide; (3) multiple impregnation; (4) mercerization of fibers before impregnation.

The amount of lead in the fibers increased approximately in proportion to the concentration of lead acetate in the impregnating solution, provided the time of exposure to hydrogen sulfide was long enough or the concentration of the gas high enough to effect virtually complete reaction. Table III shows that 90 min. in 10% hydrogen sulfide is sufficient with 10% lead acetate, but that with 40% lead acetate the sulfide concentration must be considerably increased. Raising the temperature of the lead acetate solution had little effect, and 30 min. in the solution was about as effective as 18 hrs. Placing the sample in a tube, pumping out the air, and then admitting solution to the tube did not increase appreciably the amount of lead absorbed.

Table IV shows that, for low concentrations of lead in the fibers, exposure for 30 min. to 10% hydrogen sulfide in air was sufficient to give maximum formation of lead sulfide. At higher concentrations, either the time or the proportion of hydrogen sulfide to air had to be increased (for examples see Table III).

The amount of lead was increased by multiple impregnation, but successive treatments added smaller increments (Table V). Microscopical examination of cross sections of impregnated fibers showed only a small amount of lead sulfide in the lumen or cell wall. (Silver, on the other hand, was found to be distributed throughout the fiber.) Since most of the sulfide was on the outside, it is clear why repeated treatments added less and less to the total deposit.

It was thought that swelling the fibers by mercerizing them before impregnation might increase the penetration of the lead acetate solution into the fibers and hence increase the amount of lead deposited. In parallel tests, however, mercerized fibers showed very nearly the same pickup as unmercerized ones. Under the microscope, it did appear that the lead sulfide was more uniformly distributed in the mercerized samples, but the difference was not great enough to affect significantly the absorption of x-rays.

Tables III, IV, and V show that, in general, the tensile strength of the fibers was not greatly reduced either by the impregnating process or by the presence of lead sulfide, up to about 15%. Prolonged or repeated exposure or the presence of 20% or more lead resulted in a significant decrease in the Pressley strength index.

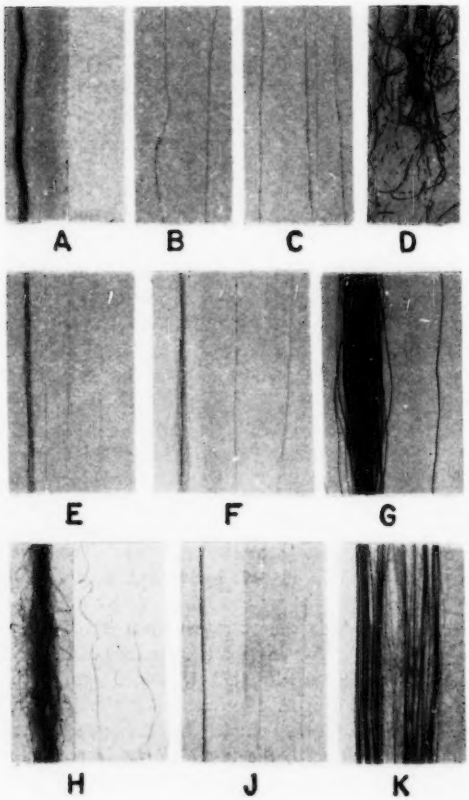

FIG. 8. *X-ray photographs of single fibers and yarns (5 kv., 33 ma., 25 cm., 40-min. exposure) (5×). A, untreated cotton yarn and single fibers; B, cotton—15% Pb; C, cotton—25% Pb; D, absorbent cotton—40% Pb; E, viscose rayon; F, viscose—5% Ba; G, viscose—30% Ba ("Ray-Tee"); H, wool yarn and single fibers; J, nylon yarn and fibers; K, Pyrex glass fibers.*

Absorption of X-Radiation by Fibers

One of the most interesting observations made during this study is that many natural and synthetic fibers absorb x-rays appreciably at 17.5 kv.; indeed, no fibers have been found that are transparent at this voltage. It was expected that radiation at this voltage would be too penetrating and that it would be necessary to use much softer radiation (5 kv. or less) before shadowgrams of untreated fibers could be obtained. Cotton, wool, nylon, viscose and acetate rayon, hemp, jute, sisal, ramie, and glass fibers have all been successfully photographed.

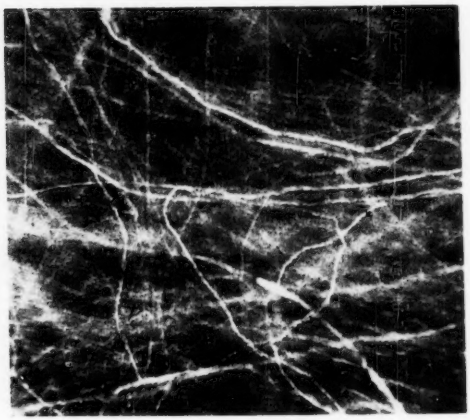

FIG. 9. *X-ray photograph of 1% blend of treated and untreated cotton fibers (150×). Treated fibers contain 14% lead as lead sulfide (15 kv., 30 ma., 28 cm., 90-sec. exposure).*

Some of these are illustrated in Figure 8, both as single fibers and as yarns; some impregnated or opacified fibers are also shown. Since differences between cotton fibers containing different amounts of lead could be observed, blends of treated and untreated cotton were made to see whether or not the marked fibers could be identified. Figure 9 is an enlargement of a typical portion of a radiograph of such a blend, with approximately 1% of fibers containing 14% lead. The matte of fibers laid on the plate was about 1 cm. thick. The treated fibers stand out against a diffuse background of untreated fibers.

Although fiber tracing has been partially successful by the method just illustrated, a few isolated marked fibers in a large matte of cotton are much harder to locate. If the untreated fibers are nearly parallel, then a few single fibers laid *across* the matte are spotted without much difficulty, but when treated and untreated are lined up alike, it is very difficult to distinguish the two. To test this point, some "standards" were made by planting a known number (1 to 10) of the treated fibers in a bundle (2 mg.) of cotton sliver, and the standards were photographed. Those containing less than 10% lead could not be picked out at all. About half of the fibers containing more than 10% lead were found without much uncertainty, and another quarter were found by one examiner and not by another. If, therefore, only about 50% of the treated fibers can be found when the entire sample covers less than 1 sq. in. (6.3 sq. cm.), the possibility of finding a few marked fibers scattered in a large mass of unmarked fibers, such as a card web, is not very great.

One source of uncertainty in dealing with individual fibers is incomplete knowledge regarding the metal content. Analytical data were obtained, of course, on samples of thousands of fibers and represent average values. When single fibers are picked out for study, the lead content may be considerably above or below the average for the mass. This may account in part for the failure to find all the marked fibers in the tests just described.

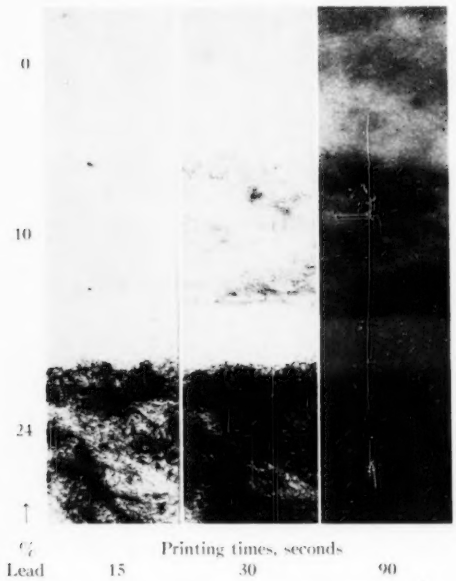

FIG. 10. *X-ray photographs of absorbent cotton impregnated with lead. Three prints made from the same plate. X-ray data: 15 kv., 30 ma., 25 cm., 90-sec. exposure.*

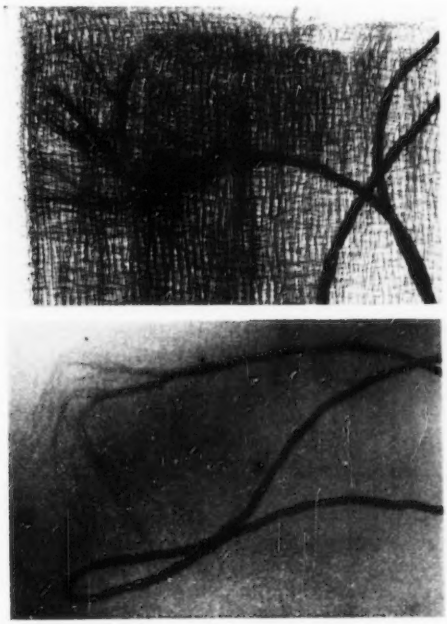

FIG. 11. *X-ray photographs of Ray-Tec surgical sponge.* Top—*With Machlett x-ray tube on spectrographic plate 548-0; 15 kv., 30 ma., 25 cm., 60-sec. exposure.* Bottom—*With G. E. portable x-ray unit on Du Pont x-ray film; 45 kv., 5 ma., ca. 33 cm., 3-sec. exposure.*

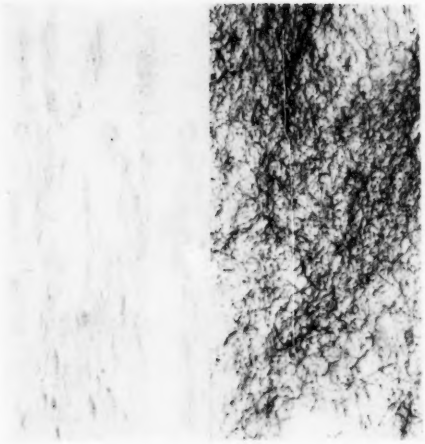

FIG. 12. *X-ray photograph of wool fibers.* Left—*untreated;* right—*soaked in 25% mercuric nitrate solution for 24 hrs.* (2.5 ×) (*7 kv., 35 ma., 25 cm., 7-min. exposure*).

Exposure is an important factor in the contrast that is obtained: short exposures tend to show up untreated fibers, whereas on long exposures the x-rays tend to "burn through" the less absorbent material. Furthermore, exposure of the final print from the plate allows considerable latitude in emphasizing or repressing the image. Figure 10 affords an example of this flexibility: the three prints shown were all made from one plate by changing the exposure time during printing. The image of unimpregnated cotton, clearly seen on the plate itself, can be virtually eliminated by shortening the printing time, and the same is true of the sample containing 10% lead. On the other hand, even at 45 kv., as shown in Figure 11, the image of untreated cotton threads is faintly visible. It is apparent, therefore, that there is a great deal of latitude both in obtaining the original x-ray image and in making prints from it; any particular detail may, to a considerable degree, be emphasized or suppressed by suitable adjustment of exposures. The nature of the x-radiation used—*i.e.*, the voltage at which the x-ray tube is operated—is less important, therefore, than had at one time been thought. Approximately the same picture can be obtained over the whole range of voltage studied, from 5 to 17.5 kv. (and possibly higher), if only the proper exposure times are used.

The problem of opacifying fibers without seriously affecting their tensile strength and surface properties is much easier to solve with rayon than with cotton. The opacifying agent (barium sulfate,

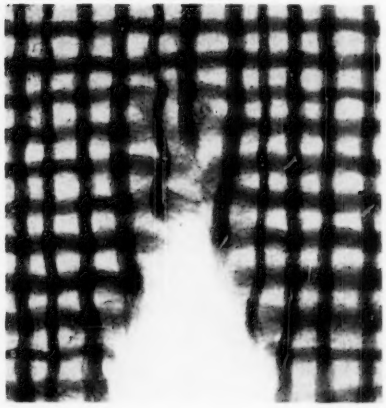

FIG. 13. *Cotton bagging* (13 ×) (*10 kv., 30 ma., 20 cm., 8-min. exposure*).

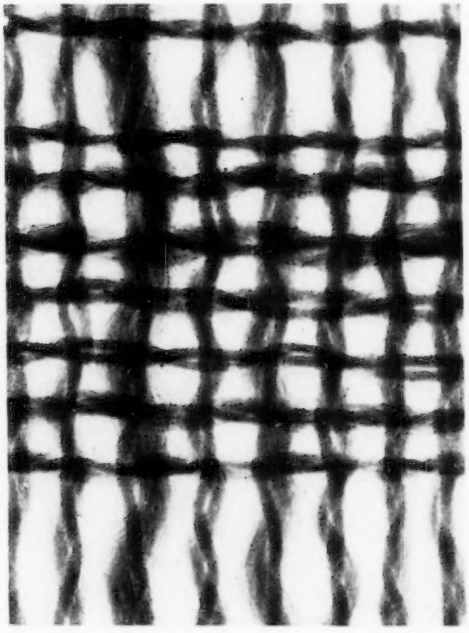

FIG. 14. *Specialty fabric* (*viscose rayon*) (13 ×) (*12.5 kv., 30 ma., 28 cm., 15-min. exposure*).

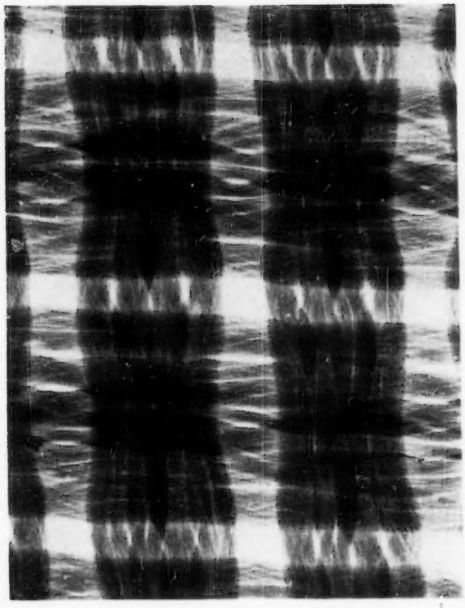

FIG. 15. *Specialty fabric (viscose rayon) (13 ×) (12.5 kv., 30 ma., 20 cm., 6-min. exposure).*

titanium dioxide, lead oxide, etc.) may be added, in a very highly dispersed state, to the rayon dope

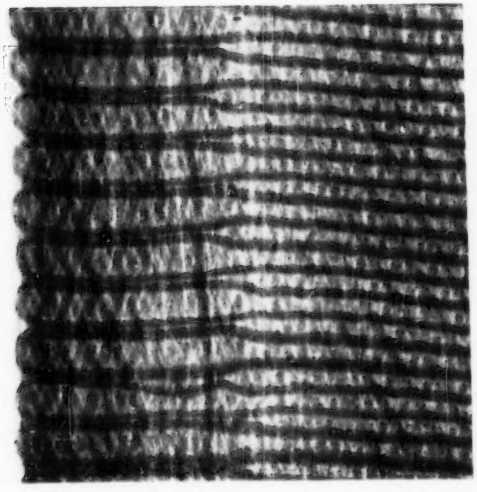

FIG. 16. *Gabardine suiting (viscose and acetate blend) (6.5 ×) (10 kv., 30 ma., 25 cm., 2-min. exposure).*

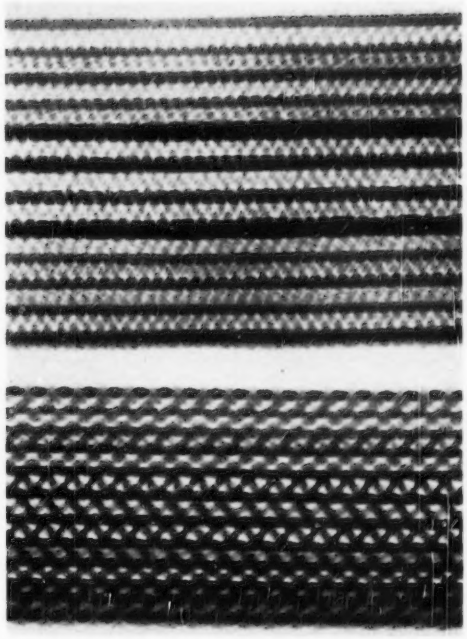

FIG. 17. *Elastic webbing.* Top—*unstretched;* bottom—*stretched to double length (6 ×) (12.5 kv., 30 ma., 20 cm., 6-min. exposure).*

before spinning. Quantities of filament viscose which contained 0, 0.5, 1.2, and 5.2% barium sulfate were obtained from the American Viscose Corporation. Distinct differences in absorption of x-rays were found in single filaments of the four samples, but the contrast between rayon containing 0 and 5.2% opacifier was not enough to permit ready identification in mixtures (see Figure 8, E, F). Higher concentrations of barium sulfate or perhaps of lead oxide might give the necessary contrast, and such rayon in staple form could probably be used in studying some of the industrial problems to be examined by the technique of microradiography.

The Johnson and Johnson Company produces a surgical sponge, "Ray-Tec," with a black rayon yarn folded in layers of gauze. The yarn contains more than 50% barium sulfate. If such a sponge is inadvertently left in the patient following an operation, it can readily be located by x-ray fluoroscopy or photography. (See also a similar use of high-lead-content glass fibers [3].) Figure 11 shows

two photographs of a Ray-Tec sponge. In the upper one, made at 15 kv., the gauze threads are very clear, although the loaded rayon filaments are much more absorbent. In the lower picture, made at about 45 kv., the cotton is only very faintly discernible, while the separate rayon filaments are still clear.

Wool soaked in a solution of a salt of mercury takes up mercury in a form that cannot be washed out subsequently, perhaps through combination with sulfur in the fiber molecule. On prolonged standing in the solution (several days), the fibers become deep red in color, the intensity depending upon the length of time of soaking. In Figure 12 are shown radiographs of untreated wool fibers and fibers soaked for 24 hrs. in a solution containing 25% mercuric nitrate.

Figures 13–17 show enlargements of microradiographs of several types of fabrics: ordinary cotton bagging, two types of specialty fabrics made of viscose rayon, gabardine suiting made of a viscose-acetate blend, and elastic webbing. In order to take the pictures the samples were simply laid on the plate under the window of the x-ray tube. The individual fibers of the yarns are clearly discerned, and the construction of the fabrics is also well shown. In Figure 17, the rubber cores are more absorbent than the surrounding cotton fabric. These examples are given to illustrate the application of microradiography to the study of fabrics; yarns and ply cords may also be profitably studied by this technique, in both stressed and unstressed states.

Summary

1. X-rays generated at 5 to 17.5 kv. (wave length 1–3 A.) have been used for microradiography of single fibers. Fine-grain spectrographic plates with a resolving power in excess of 500 lines per mm. gave shadowgrams which permitted enlargements up to 100 times.

2. Clear images of cotton, acetate and viscose rayon, wool, nylon, bast, and glass fibers were obtained.

3. For satisfactory definition the distance from x-ray tube to object should be at least 20 times that from object to photographic plate.

4. Impregnation of fibers with 10–20% lead sulfide increases absorption of soft x-rays so that they can be distinguished from untreated fibers. In blends, such fibers are clearly discernible in x-ray photographs at 15 kv. when laid across the untreated fibers, but, side by side, they can scarcely be distinguished with assurance in more than about half the cases. In 1% blends of treated and untreated fibers, the former are clearly visible, and the proportion could probably be lowered considerably without losing sight of the marked fibers.

5. Rayon fibers can be made highly absorbent of x-radiation by the addition of opacifying agents such as barium sulfate to the dope before spinning. Such fibers may be very useful as tracers in studying textile processes.

6. Microradiography provides insight into the construction of fabrics and yarns.

Acknowledgments

The cooperation of our colleagues, Dr. William T. Ham, Jr., and Dr. E. J. Bernet, in setting up the x-ray tube, in adapting the radar unit for this application, and in making many valuable suggestions during the course of the investigation is gratefully acknowledged. Mr. W. C. Gregory carried out most of the impregnation tests with lead compounds. Mr. H. A. Mereness and Miss Ann Jones determined the tensile strength of many specimens. Mr. T. L. W. Bailey, Jr., and Miss Anne Miller cross-sectioned and examined cotton fibers used for penetration by the impregnating material. Mr. J. C. Burnett assisted in the photographic work.

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Cellulose Studies*

XII. The Degree of Polymolecularity of Acid-Modified Celluloses

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Contribution from the Textile Foundation and the Frick Chemical Laboratory, Princeton University

Abstract

For the determination of the degree of polymolecularity in acid-modified celluloses the nitrates of hydrocelluloses from native cotton, surgical cotton, and viscose rayon were fractionated from dilute acetone solutions. The results indicate that a large proportion of the hydrocelluloses are uniform in that almost 33% of the methanolyzed native cotton consists of molecules with D.P. 252, about 70% of the hydrocellulose from surgical cotton has D.P. 260, and some 36% of the material from viscose rayon possesses D.P. 62. Moreover, the most important fractions were found to be integral multiples of the assumed "limit hydrocellulose" with D.P. 64. Integral- and mass-distribution curves were constructed from the experimental data according to the procedure outlined by Schulz and were compared with the theoretical mass-distribution curves calculated on the basic assumption of random hydrolysis of a long-chain molecule with uniform hydrolyzable bonds. In all three cases the experimental curves show pronounced peaks, which can be readily interpreted only on the basis of the new concept of cellulose structure.

IN ORDER TO TEST the validity of the new concept of cellulose structure [5] it is essential that the degree of polymolecularity of the various hydrocelluloses be determined. Directly contradictory results would be expected according to the old and the new concepts of cellulose structure. If cellulose consisted only of a long chain of glucose-anhydride residues held together by "uniform and equivalent, covalent glycosidic linkages," then a partial acidic degradation would result in a *random* scission of the long-chain molecules; hence, the cellulose would be expected to be less and less uniform as the degradation proceeded. On the other hand, the new concept postulates that hydrolysis should take place at preferred, *equidistant* spots in the cellulose molecule, and therefore the material should increase in uniformity as the hydrolysis progresses and the "limit hydrocellulose" would be expected to be more or less uniform.

For the determination of the degree of polymolecularity the nitrates of the following three typical hydrocelluloses were fractionated: (*a*) viscose rayon hydrolyzed with 1*N* hydrochloric acid at 60°C for 12 hrs. and showing D.P. 65 in cuprammonium solution; (*b*) surgical cotton hydrolyzed with 1*N* hydrochloric acid at 60°C for 18 hrs. and having D.P. 270 in cuprammonium solution; (*c*) native cotton degraded with 43% methanolic hydrogen chloride at 0°C for 24 hrs. and having D.P. 260 in cuprammonium solution.

A description of the methanolysis experiment was given in Paper XI [4].

The hydrocelluloses were nitrated at 0°C for 4 hrs. with a mixture of fuming nitric acid (89%), glacial phosphoric acid (85%), and phosphoric anhydride in the ratio 48:50:2 (by weight), in accordance with the procedure outlined by Davidson [2]. Approximately 50 ml. of the nitrating mixture was used for 1 gram of the material. At the end of the nitration, the product was filtered with suction on a fritted glass funnel, and by pressing the nitrate with the flat end of a glass rod most of the acid was removed. The nitrate was then steeped in distilled water, changing the water a number of times, and finally was washed on a Buchner funnel with hot water and dried over solid potassium hydroxide in a desiccator.

The nitrates were examined for their nitrogen content by the "nitron" method [1]. When nitro-

* The first paper in this series appeared in the October, 1945, issue of Textile Research Journal. Papers II–VIII were published in March, April, June, July, August, October, and November, 1946. Paper IX appeared in the August, 1947, and Paper X in the July, 1948, issues, and Paper XI in the October, 1949, issue.

TABLE I. FRACTIONATION OF CELLULOSE NITRATE FROM NATIVE COTTON METHANOLYZED WITH 43% METHANOLIC HCl AT 0°C FOR 24 HRS. (AVERAGE D.P. 312 FOR THE NITRATE)

Fraction No.	Weight (g.)	Percent	D.P. = 270 × [η]	Number of $2^6 = 64$ units; D.P. calculated
1	0.03	0.55	—	—
2	2.15	39.74	525	8 (512)
3	1.77	32.72	252	4 (256)
4	0.46	8.50	182	3 (192)
5	0.26	4.81	84	1 (64)
6	0.17	3.12	65	1 (64)
7	0.06	1.10	—	—
Subfractionation of Fraction No. 2 (1.54 g.)				
1	0.82	53.2	546	8 (512)
2	0.63	40.9	520	8 (512)

TABLE II. FRACTIONATION OF CELLULOSE NITRATE FROM SURGICAL COTTON HYDROLYZED WITH 1*N* HCl AT 60°C FOR 18 HRS. (AVERAGE D.P. 286 FOR THE NITRATE)

Fraction No.	Weight (g.)	Percent	D.P. = 270 × [η]	Number of $2^6 = 64$ units; D.P. calculated
1	0.34	8.50	546	8 (512)
2	0.53	13.25	260	4 (256)
3	1.87	46.75	260	4 (256)
4	0.40	10.00	261	4 (256)
5	0.21	5.25	208	3 (192)
6	0.32	8.00	166	3 (192)
7	0.14	3.50	70	1 (64)

TABLE III. FRACTIONATION OF CELLULOSE NITRATE FROM VISCOSE RAYON HYDROLYZED WITH 1*N* HCl AT 60°C FOR 12 HRS. (AVERAGE D.P. 60 FOR THE NITRATE)

Fraction No.	Weight (g.)	Percent	D.P. = 270 × [η]	Number of $2^6 = 64$ units; D.P. calculated
1	0.81	32.4	162	2 (128)
2	0.29	11.6	81	1 (64)
3	0.28	11.2	62	1 (64)
4	0.61	24.4	62	1 (64)
5	0.20	8.0	53	1 (64)
6	0.11	4.4	—	—

cellulose is saponified with alkali, there are formed alkali nitrates, nitrites, and a small amount of ammonia. The formation of nitrites and ammonia is prevented by the presence of hydrogen peroxide. The whole of the nitrogen content is then obtained as nitrate, upon acidifying, and may be estimated quantitatively by using "nitron" (diphenyl-endanilodihydrotriazole). A nitrogen content of about 12.7–13% was obtained for the products analyzed by this method.

For the fractionation, the nitrated hydrocelluloses were dissolved in acetone to give approximately 1% solutions. Fractionation was carried out in the liquid phase, according to the procedure of Schulz [6], in the following manner:

The flask containing the acetone solution of the nitrate was immersed in a constant-temperature water-bath at 25° C, and enough distilled water (also brought to 25°C) was added to produce a light turbidity. The solution was then left for 2 to 3 days in the bath, the less soluble fraction separating out in the form of viscous, liquid drops at the bottom of the flask. The clean, supernatent solution was transferred to another flask and the fractionation continued. The less soluble fraction was precipitated from the viscous liquid by addition of distilled water, filtered out with suction, and dried over solid potassium hydroxide in a desiccator. Six to seven fractions were obtained in this manner and their degrees of polymerization were determined by measuring their viscosities in acetone solution. From each fraction three to five solutions with different concentrations were prepared and the viscosities were measured at 25° ± 0.1 C in an Ostwald-Fenske type of viscometer. By graphic extrapolation of the data to infinite dilution, $\frac{\eta_{sp}}{C}$ *vs.* C—where *C* denotes grams per 100 ml.—the intrinsic viscosities, [η], were obtained, which were converted into the D.P. values by multiplying by 270, according to the method of Kraemer and Lansing [3].

The results of fractionation, given in Tables I, II, and III, indicate two significant features:

In the first place, a large proportion of the material is uniform and shows a D.P. of about 260 in the case of cotton and 62 in the case of viscose rayon. Thus, almost 33% of the methanolyzed native cotton has a D.P. of 252. The hydrocellulose from surgical cotton has even a larger fraction of this degree of polymerization—*viz.*, three fractions totaling 70%, with D.P. 260. In the fractionation of the hydrocellulose nitrate from viscose rayon some 36% of the material is uniform, with a D.P. value of 62. Subfractionation of the large fraction (No. 2 (40%)) with D.P. 525, in the case of the methanolyzed native cotton, does not result in significant variations of the D.P. values (546 and 520) of the subfractions, thus indicating the uniformity of the product.

TABLE IV. DATA FOR CONSTRUCTION OF THE INTEGRAL- AND MASS-DISTRIBUTION CURVES FOR MATERIAL DERIVED FROM METHANOLYZED NATIVE COTTON (TABLE I) (AVERAGE D.P. 312)

Fraction No.	Percent	Cumulative weight percent	$I(P) \times 10^2$	D.P. obs.
1	4.22	4.22	2.11	65
2	4.81	9.03	6.62	84
3	8.50	17.53	13.28	182
4	32.72	50.25	33.89	252
5	39.74	89.99	70.12	525
6	0.55	90.54	89.99	—

TABLE V. DATA FOR CONSTRUCTION OF THE INTEGRAL- AND MASS-DISTRIBUTION CURVES FOR MATERIAL DERIVED FROM HYDROLYZED SURGICAL COTTON (TABLE II) (AVERAGE D.P. 286)

Fraction No.	Percent	Cumulative weight percent	$I(P) \times 10^2$	D.P. obs.
1	3.50	3.50	1.75	70
2	8.00	11.50	7.50	166
3	5.25	16.75	14.12	208
4	70.00	86.75	51.75	260
5	8.50	95.25	86.75	546

These results cannot be reconciled with the postulate of random hydrolysis or methanolysis, a logical conclusion derived from the molecular-chain theory of cellulose structure which permits the presence only of "uniform and equivalent, covalent glycosidic linkages." If the molecular-chain theory were correct then the fractions would show perfectly random distribution and certainly would not indicate pronounced peaks at any particular D.P. values.

The second interesting characteristic is a marked periodicity of the D.P. values of the various fractions. Taking $2^6 = 64$ as the basic unit of "limit hydrocellulose," [5] it can be seen from Tables I, II, and III that the most important fractions are approximately integral multiples of that unit. In the case of surgical cotton it is particularly striking that fractions between D.P. 260 and 546 are absent and that the latter D.P. value is about double the former figure.

The significance of these results regarding the surprisingly small degree of polymolecularity in the various hydrocelluloses is brought out more clearly by plotting the theoretical and experimental distribution curves (Figures 1, 2, and 3). The method, originally that of Schulz [7], is described below in detail.

TABLE VI. DATA FOR CONSTRUCTION OF THE INTEGRAL- AND MASS-DISTRIBUTION CURVES FOR MATERIAL DERIVED FROM HYDROLYZED VISCOSE RAYON (TABLE III) (AVERAGE D.P. 60)

Fraction No.	Percent	Cumulative weight percent	$I(P) \times 10^2$	D.P. obs.
1	12.4	12.4	6.2	53
2	35.6	48.0	30.2	62
3	11.6	59.6	53.8	81
4	32.4	92.0	75.8	162
5	8.0	100.0	92.0	—

Curve ⊙ in the Figures 1 to 3 represents the integral-distribution curve, which gives the variation of the function $I(P)$ with P, the latter being the degree of polymerization (D.P.) of the fraction. The fractionation data are tabulated (Tables IV, V, and VI) in the order of increasing D.P. values, and the cumulative weight percentages are calculated for each fraction so that these values give the amount of material below the corresponding D.P. in the total amount. The value of $I(P) \times 10^2$ for the first fraction is one-half of the weight percent, whereas for each of the subsequent fractions $I(P) \times 10^2$ represents the average of the cumulative weight percent of that fraction and that of the preceding one. From the integral-distribution curve, by graphical differentiation, one obtains the experimental mass-distribution curve (●).

For comparison of the experimental mass-distribution curve (●) with the theoretical mass-distribution curve (×) use is made of the equation:

$$m_p = P\left(\frac{\beta - 1}{Po}\right)^2 e^{-P(\beta-1)/Po}\left(1 + \frac{2}{\beta - 1} - \frac{P}{Po}\right),$$

which is derived on the assumption that $Po > 100$ and that all bonds have the same probability of splitting. Po denotes the D.P. of the original material—*e.g.*, 3,000 for cellulose, regardless of the state of hydrolytic degradation of the starting material (thus Po for viscose rayon is still 3,000). P represents the number-average D.P. of the degraded product after nitration (determined with the aid of osmotic-pressure measurement), and $\beta = \frac{Po}{P}$. Thus, $\beta = \frac{3,000}{312} = 9.6$ for the nitrate from the methanolyzed native cotton, $\beta = \frac{3,000}{286} = 10.5$ for that from the hydrolyzed surgical cotton, and $\beta = \frac{3,000}{60} = 50$

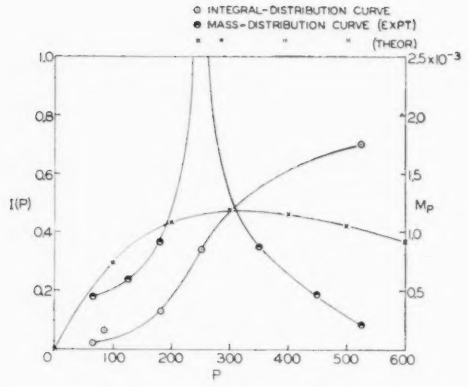

FIG. 1. *Distribution curves for material derived from methanolyzed native cotton (Tables I and IV).*

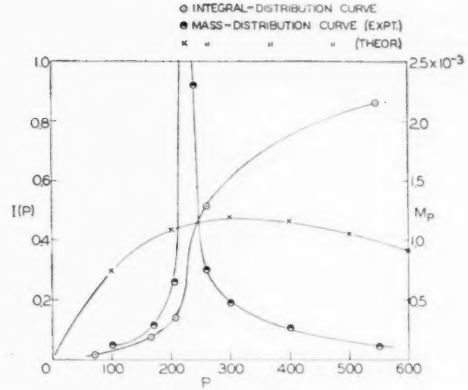

FIG. 2. *Distribution curves for material derived from hydrolyzed surgical cotton (Tables II and V).*

for the nitrate obtained from the hydrolyzed viscose rayon. In order to calculate the theoretical mass distribution over various D.P.'s, various values for P—*e.g.*, 20, 40, 60, 100 . . . in the case of viscose hydrocellulose—are substituted in the equation for m_p. The number-average D.P. of the degraded product—60 in the case of the nitrate from viscose rayon—is used only for calculating β. The values of m_p are then plotted against D.P. (Curve $\times$ in Figures 1, 2, and 3) and the curves so obtained represent the theoretical mass distribution of a material which contains only one uniform type of hydrolyzable bonds.

Inspection of these curves ($\times$) clearly shows the deviation of the experimental results from the theoretical assumption of a random hydrolysis and of an equal probability of cleavage of all hydrolyzable bonds in the cellulose molecule. The experimental curves (●) in all three cases show pronounced peaks (at D.P. ~ 200 for cotton and D.P. ~ 60 for viscose rayon), whereas the theoretical curves show a distribution over a fairly wide range of D.P. values.

We take these results of fractionation as convincing evidence for the new concept [5] of cellulose structure. If it be true that in the cellulose molecule there are chains of 64 glucose-anhydride units connected by weak, acid-sensitive acetal bonds ([4], Formula I), it is obvious that, upon hydrolysis and fractionation, the fractions would show D.P. values which are integral multiples of that unit. This is to be expected because the acid attacks these weak bonds first, leaving chunks of the cellulose molecule of D.P. $64 \times n$, where n is an integer the value of which depends upon the extent of the hydrolysis and upon the accessibility of the acid-sensitive bonds. It is also evident that as the hydrolysis proceeds—that is, as more and more weak bonds split—the material progressively becomes more uniform and ultimately reaches the limiting value, which appears to be about $4 \times 2^6 = 256$ for native cotton and $2^6 = 64$ for regenerated celluloses. This simply means that the "limit hydrocellulose" from native cotton still contains acid-sensitive linkages which, however, occur in regions inaccessible to the acidic reagents. The value of $2^6 = 64$ has been chosen as the probable value of the degree of polymerization of a *chain molecule* supposedly free of acid-sensitive linkages

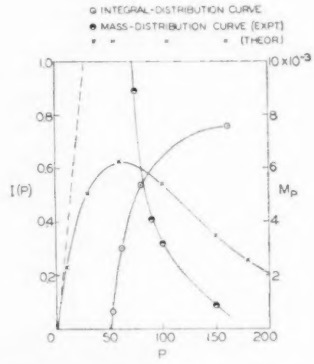

FIG. 3. *Distribution curves for material derived from hydrolyzed viscose rayon (Tables III and VI).*

because we have not yet been able to obtain from any cellulosic material a primary degradation product with a lower value.

Finally, it should be pointed out that the experimental results obtained in this work are in excellent agreement with the conclusions drawn from the experimental results presented in Paper XI [4].

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Pore-Size Distribution in Textiles—A Study of Windproof and Water-Resistant Cotton Fabrics*

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Abstract

A modified method for evaluating the distribution of pore spaces within a textile fabric, based on the principle outlined in the preceding paper in this series [1], is described. Data are reported for 14 tight fabrics, 6 of which had been treated with a water-repellent finish. The porosities of these fabrics are compared with the results of air- and hydrostatic-permeability measurements.

Introduction

In designing and manufacturing windproof and water-resistant fabrics, textile designers and weavers have endeavored to make the holes in the cloth as small as possible. The success of their efforts has been evaluated by a variety of air-permeability and water-resistance tests, all of which yield only relative values without indicating the true nature of the openings responsible for fluid passage. There is, therefore, the need for an independent physical method whereby the porosity of fabrics of various designs can be studied.

Such a method has been described in the preceding publication [1]. In it, a method of mercury displacement is employed to obtain a fairly complete picture of the distribution of pore spaces within the textile material. The present paper is an extension of this work as it was carried out at the Institute of Textile Technology. Here is described a more rapid test covering a wider range of pore radii than were previously measured. By this modified method results have been obtained on the pore-size distributions in 14 tight, experimental cotton fabrics.

For the complete theory of the method, the reader is referred to the preceding paper [1] or to the earlier publication by Ritter and Drake [3]. In this theory, the relationship for the pressure required to force liquid into a pore of given size—namely

$$pr = -2\sigma \cos\theta, \qquad (1)$$

where p is the pressure, r the pore radius, σ the

* The first article in this series appeared in the September, 1949, issue.

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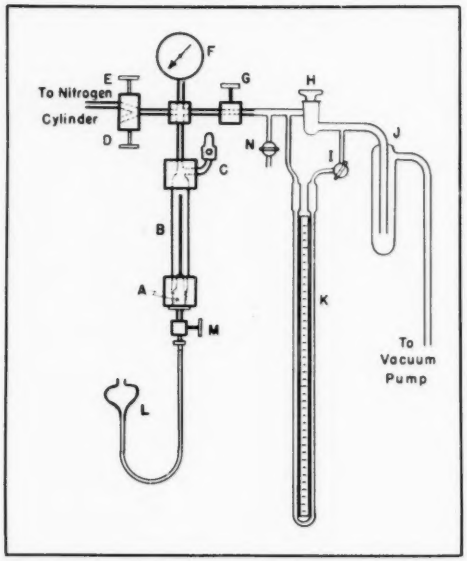

FIG. 1. *Schematic diagram of porosimeter.*

surface tension, and θ the contact angle—is used to derive a distribution function for pore size. This function, $D(r)$, is of such a nature that the area under the curve of $D(r)$ plotted against r and between any two values of r gives the volume of pore space for all pores having radii between those limiting r values. The distribution function is evaluated from the equation

$$D(r) = \frac{p}{r}\frac{d(V_0 - V)}{dp}, \qquad (2)$$

in which all the terms on the right are known or determinable. (The quantity $(V_0 - V)$ is the change in volume of the liquid-solid system as pressure is applied.)

The method of calculation used in the present work was identical with that used earlier except for the fact that the value of 180° was used as the contact angle between mercury and the cotton fiber in equation (1). This choice is based on an extensive study of contact-angle theory and measurement for both wetting and nonwetting liquids and is believed to be better than the choice of 140°, which was used heretofore. The result of this choice is an increase of about 25% for the minimum pore radii values. Because the change is by a constant factor, the shape of the distribution curve will not be appreciably affected.

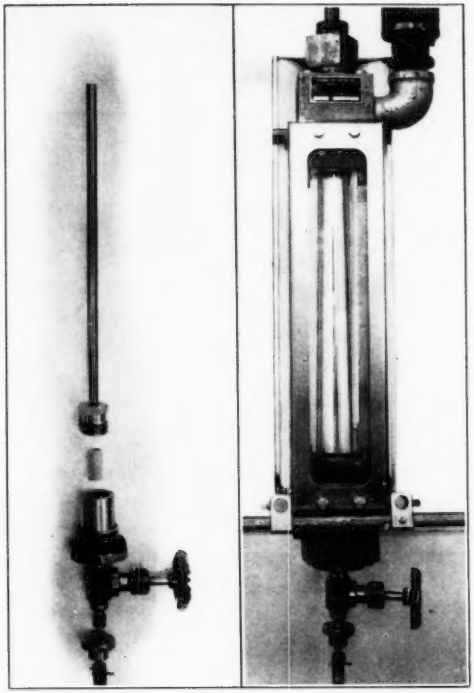

FIG. 2. *Volumenometer* (A) (left) *and pressuring housing* (B) (right).

Experimental Procedure

Experimentally, the problem of obtaining data from which the pore distribution can be calculated is one of measuring the changes in total volume of a system composed of textile fabric immersed in mercury when the system is subjected to increasing external pressure. In the present apparatus, volume changes are measured in a stainless-steel volumenometer with a calibrated glass capillary. The volumenometer is placed in the glass pressure flowmeter housing of the porosimeter and subjected to nitrogen gas pressure from 0 to 200 lb. per sq. in., absolute (p.s.i.a.). The volume of mercury and fabric in the volumenometer is determined from the height of mercury in the capillary as measured with a cathetometer.

Figure 1 is a diagrammatic presentation of the apparatus used. The fabric sample is placed in the

volumenometer (*A*) (also shown in Figure 2), which screws into the pressure housing (*B*) (Figure 2). The latter also contains a thermometer for recording the temperature of the system and a safety relief valve (*C*) set at 200 p.s.i. (gage). Pressure connections to the volumenometer housing lead through valve (*D*) to the atmosphere, through valve (*E*) to a cylinder of high-pressure nitrogen, to a precision test gage (*F*), and through valve (*G*) to the vacuum system. The vacuum is produced by a high-capacity mechanical pump located beyond trap (*J*). Pressures from 0 to about 20 p.s.i.a. are read on the manometer (*K*).

The volumenometer proper consists of three parts (see Figure 2): a stainless-steel cylinder for holding the fabric sample immersed in mercury, a pressure needle valve at the bottom of the cylinder for admitting the mercury, and a calibrated glass capillary, open at the top and attached to a steel collar which screws into the top of the cylinder. The capillary, of about 2 mm. internal radius, is calibrated for volume of mercury at any height above a fixed reference line.

In operation, a 1-g. strip of the fabric to be tested, either dry or moist, is rolled into a small cylinder about 1 cm. in diameter and placed within the volumenometer cylinder. The capillary and cap are screwed tightly into place, the unit is then screwed into the pressure housing, and the mercury tube is attached to the volumenometer valve. The reference side of the manometer is first evacuated with stopcock (*H*) closed and with stopcock (*I*) open. When this part of the system is exhausted as completely as possible, (*I*) is closed and (*H*) is opened, with (*G*) and (*M*) open and (*D*), (*E*), and (*N*) closed. While the system is thus being evacuated, the mercury leveling bulb (*L*) must be more than 76 cm. below valve (*M*) in order to prevent mercury from filling the volumenometer. After evacuation, bulb (*L*) is carefully raised until the mercury level is near the top of the capillary. Valves (*M*) and (*H*) are then closed and (*I*) is reopened.

The system is now ready for the pressuring operation. This is accomplished first by bleeding in air through valve (*D*). At intervals this process is stopped for readings of the pressure by means of the manometer and of the mercury height in the capillary by means of a cathetometer. When atmospheric pressure is reached, (*D*) is closed and nitrogen under pressure is bled into the system through (*E*) up to a gage reading of about 5 p.s.i. At this point (*G*) is closed and (*N*) is opened to relieve the pressure on one side of the glass manometer. More nitrogen is then admitted through (*E*) until the gage reads 180 p.s.i. when the pressure on the mercury-fabric system is about 200 p.s.i.a.

The total pressure on the mercury-sample system is the sum of the imposed gas pressure plus the pressure due to the column of mercury above the sample. The determination of $(V_0 - V)$ is made from the corresponding $(h_0 - h)$ values read with the cathetometer and a calibration curve previously prepared for the particular capillary used. These data are then plotted on $(V_0 - V)$ *vs.* pressure curves such as those shown in Figure 3. The tangent, or $d(V_0 - V)/dp$, values are read at various pressures by means of an adjustable quadrangle. This device consists essentially of a pair of straight edges hinged at the center of a protractor for the purpose of reading the angle or slope which the edges make with each other. The pore-size distribution function is calculated from these slopes, as outlined earlier [1].

The final distribution curve yields three types of useful information concerning pore spaces in a fabric sample. The distribution function is of such a nature that the area under the curve between any two values of r (pore radius) gives the volume of pore space for all pores having radii between the

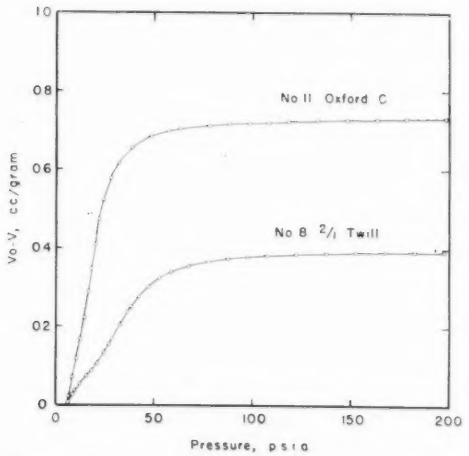

FIG. 3. *Typical pressuring curves for textile fabrics.*

TABLE I. PHYSICAL PROPERTIES OF FABRIC SAMPLES INVESTIGATED

Sample no.	Description	Nominal yarn no. Warp	Nominal yarn no. Filling	Thread count Warp	Thread count Filling	Weight (oz./sq. yd.)	Thickness in 1/1000 in.	Air permeability*	Hydrostatic permeability Height†	Hydrostatic permeability Flow‡
Group I										
1	Plain weave	13/1	10/1	82	52	9.2	20	2.56	—	—
2	Oxford	13/1	10/1	85	54	9.7	22	3.41	—	—
3	Sateen	13/1	10/1	84	71	11.2	30	5.10	—	—
4	Herringbone twill	13/1	10/1	82	64	10.6	23	2.19	—	—
5	Modified herringbone twill	13/1	10/1	82	63	10.6	24	2.17	—	—
Group II										
6	2/1 Twill, ¾-in. average cotton	13/1	10/1	82	53	9.8	24	5.83	10	>10,000
7	2/1 Twill, 1-in. average cotton	13/1	10/1	82	53	9.3	23	5.70	—	—
8	2/1 Twill, ¾-in. coarse cotton	13/1	10/1	82	53	9.4	23	7.07	—	—
Group III										
9	Oxford A	80/2	40/2	166	81	6.6	13	1.57	54	1,219
10	Oxford B	80/3	40/3	136	63	8.3	16	1.58	54	801
11	Oxford C	80/3	40/3	159	64	9.0	17	0.80	80	65
12	Oxford D	60/3	45/3	142	63	9.5	18	0.84	68	397
13	Oxford E	60/3	30/3	140	52	10.0	20	1.00	75	307
14	Oxford F	30/3	15/3	82	39	13.3	25	1.21	50	846

* Air flow in cu. ft./sq. ft./min.
† Hydrostatic pressure in cm. of water on the fabric.
‡ Permeability in water flow in cc. through a 5½-in. circle in 50 min.

two r values. The area under the whole curve gives the total pore volume up to the maximum value of r measured. Inspection of the curve affords an estimate of the median pore radius—the radius corresponding approximately to the peak of the distribution curve. Finally, the curve shows whether the pore volume is limited to pores of a narrow range of radii or whether it includes pores of a wide band of radii values.

For the porosity determinations on moist fabrics the samples were first dried to determine their dry weight and then conditioned to some moisture level about 5% over the moisture content desired for the experiment. This additional moisture was added to compensate for the loss which occurs during the initial evacuation of the volumenometer. Control experiments were performed to obtain data on rates of moisture loss in evacuation of samples with different initial moisture contents. From these experiments it is possible to predict fairly accurately the amount of moisture in the sample at the time of immersion in the mercury and during the test.

Physical properties of the fabric samples investigated were determined in the testing laboratory of the Institute. They are summarized in Table I.

Total free-space volume, V_f, for the fabric is calculated from the weight, w, per unit area, a, of the fabric, the micrometered thickness, t, at 1 lb. sq. in. pressure, and the density of the cotton fiber, d_f, according to the formula:

$$V_f = \text{volume of fabric} - \text{volume of fibers};$$
$$V_f = at - w/d_f.$$

The fiber density values used are those obtained for the whole fiber in mercury reported by Wakeham [4].

Fabric Samples

Three groups of fabric samples were investigated (see Table I).

Group I fabrics all were made of the same warp and filling yarns but with different weave patterns. In each case, the fabric texture was designed to include the maximum weavable number of filling yarns per inch. The warp yarns were 13's and the filling yarns 10's, both of 1-in. cotton of average strength (about 80,000 lb./sq. in., Pressley strength) and average fineness (about 4.5 μg. per in.). The fabrics had been desized and Sanforized.

Group II consisted of three 2/1 twill fabrics made of 13/1 (warp) and 10/1 (fillings) yarns of different cottons: one of 7/8-in. average cotton (4.4 μg. in.); one of 1-in. average cotton (4.6 μg./in.); and one of 7/8-in. coarse cotton (5.4 μg. in.)—all of average strength. The corresponding yarns in each finished fabric had about the same twist mul-

TABLE II. FABRIC POROSITY DATA

Sample no.	Description	Specific volume of fabric (cc./g.)	Total free volume (cc./g.)	Interfiber pore volume (cc./g.)	Volume of interyarn spaces (cc./g.)	Median diameter of interfiber pores (μ)
Group I						
1	Plain weave	1.69	1.02	0.503	0.52	9.0
2	Oxford	1.70	1.04	0.600	0.44	10.4
3	Sateen	2.04	1.37	0.828	0.54	14.0
4	Herringbone twill	1.70	1.03	0.609	0.42	10.0
5	Modified herringbone twill	1.65	0.98	0.592	0.39	10.2
Group II						
6	2/1 Twill, ¾-in. average cotton	1.93	1.27	0.770	0.50	13.2
7	2/1 Twill, 1-in. average cotton	1.92	1.25	0.686	0.57	12.6
8	2/1 Twill, ¾-in. coarse cotton	1.94	1.27	0.732	0.54	14.8
Group III						
9	Oxford A	1.55	0.88	0.440	0.44	9.6
10	Oxford B	1.57	0.90	0.477	0.43	10.2
11	Oxford C	1.45	0.78	0.386	0.40	8.0
12	Oxford D	1.47	0.81	0.386	0.42	8.6
13	Oxford E	1.54	0.87	0.420	0.45	9.0
14	Oxford F	1.46	0.79	0.518	0.28	10.0

tiple: 4.8 for the warp and 4.3 for the filling yarns. All fabrics had been desized and Sanforized.

Group III fabrics were all Oxford weaves of different textures and weights and were designed to be water-resistant fabrics. They were made of $1\frac{1}{4}$-in. Wilds cotton combed yarns which had been mercerized before weaving. The final fabrics had been desized, repellent-treated with Norane, and Sanforized in the finishing process.

Results and Discussion

The results obtained are summarized in Table II and in Figures 4 to 8.

It will be noted from the pore-space distribution curves that a large volume of space in the fabric interstices is in openings of from 1 to 15 μ in radius. In all cases the $D(r)$ values are still decreasing as the radius approaches the limit of measurement—about 25 μ. This fact has suggested the arbitrary designation of 50 μ as the upper limit of diameter of *interfiber* pores, as distinguished from interyarn openings.

Microscopic observations and measurements of the observable interfiber and interyarn spaces in fabrics have supported the distinction between these two types of pores. When interyarn pores are appreciably smaller than 50 μ in diameter, they are no longer recognizable as interyarn openings because cotton fibers 20 μ or so in diameter constitute the interyarn-pore walls. In Table II, therefore, the interfiber pore volume is that for all pore spaces in the fabric less than 50 μ in diameter.

The difference between the total free volume in the fabric and the interfiber pore volume has been designated the volume of interyarn spaces. In view of the fact that all fabrics studied in this investigation were tight fabrics with practically no observable interyarn pores through the fabric, the interyarn volumes shown in Table II may appear to be rather large. This result is due to the definition of the total free volume in the fabric. The reader will recall that these total free volumes are based on a thickness measurement with a pressure of 1 lb./sq. in. on the fabric. At this pressure the fabric undergoes only a slight compression or distortion, and the total free volume, therefore, includes interyarn spaces which are due to the surface unevenness of the fabric (such as ridges and mounds) in addition to the spaces between yarns and pores within. The interyarn volume as given in Table II includes, therefore, interyarn "pores" parallel to the fabric surface as well as those perpendicular to it.

These interyarn spaces are all filled with mercury in the volumenometer before actual pressuring is begun. The column of mercury in the volumenometer exerts an initial absolute pressure of about 5 lb. sq. in. on the mercury adjacent to the fabric and, according to theory, causes all accessible pores

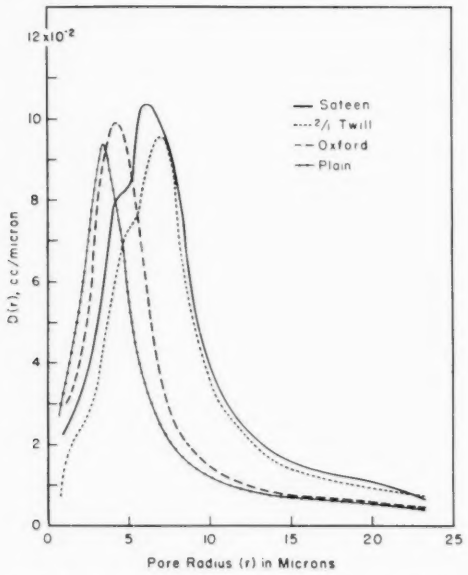

FIG. 4. *Pore-space distribution curves for typical Group I and Group II fabrics.*

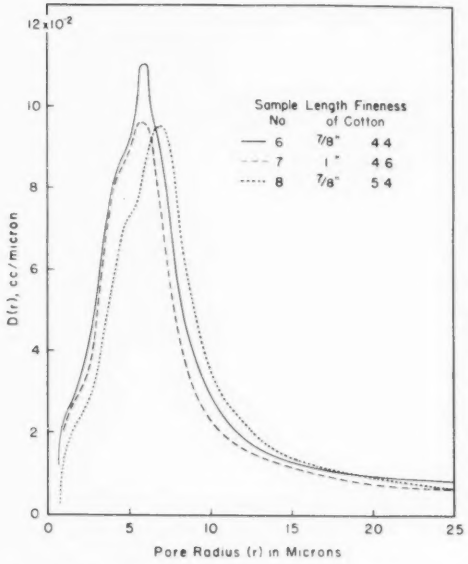

FIG. 5. *Pore-space distribution curves for 2/1 twill fabrics.*

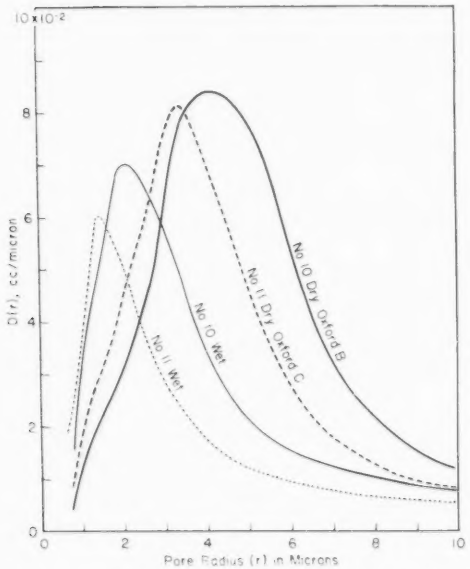

FIG. 6. *Pore-space distribution curves for Group III Oxford fabrics showing effect of 25% moisture on size of pore spaces.*

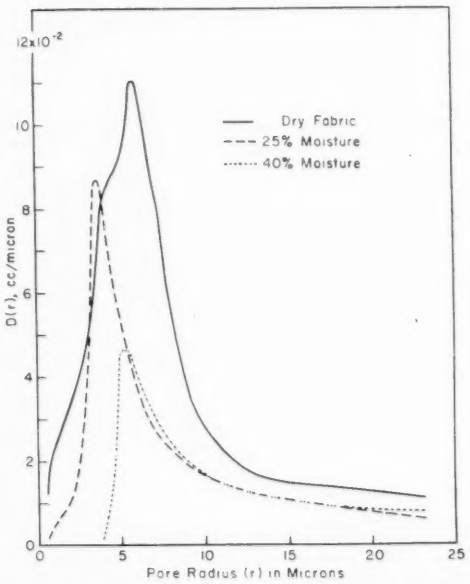

FIG. 7. *Pore-space distribution curves for 2/1 twill showing effect of moisture on size of pore spaces.*

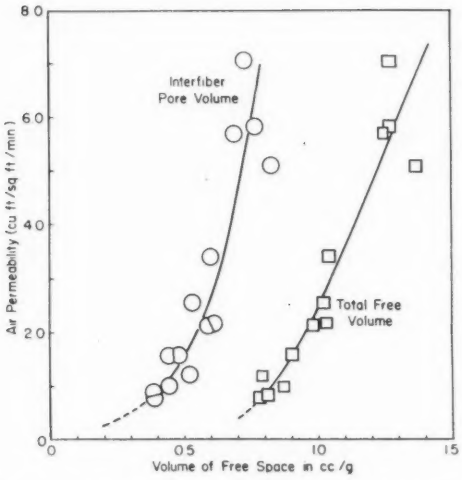

FIG. 8. *Relationships between volume of fabric pore space and air permeability.*

larger than 55 μ in diameter (27.5 μ radius) to be filled with mercury. The interyarn spaces, therefore, will not be included in the volume of pore space measured by the porosimeter.

The pore-space distribution curves may now be considered in the light of the definitions indicated above. The curves for different types of dry fabric plotted in Figures 4 to 7 show easily recognizable differences characteristic of the fabric weave, texture, and fiber content. Figure 4, for example, demonstrates that there are radical differences in pore-space distribution between a plain weave, a sateen, an Oxford, and a 2/1 twill, all woven as tightly as possible from the same warp and filling yarns. Obviously, the Oxford and the plain weave have smaller pores with less pore volume than the sateen or the 2/1 twill. These smaller pores are responsible for lower air permeability, as the data in Table I indicate.

The results for Group II fabrics, plotted in Figure 5, suggest that the method outlined may be sufficiently sensitive to indicate differences due to length and fineness of the cotton fiber used. They suggest that, at least for a 2/1 twill construction, a tighter fabric can be obtained with longer and finer cotton used as the raw material. This conclusion should be tested with other weaves, such as the Oxford types, which are inherently less porous for other reasons.

The median radius of interfiber pores (diameters are given in Table II) was calculated as a rough indication of the predominant pore size in the fabric. This median is a measure of the central tendency of the pore-space distribution curve. It is defined as the pore radius at which the areas under the $D(r)$ *vs.* r curves are equal for all higher and all lower radii. In other words, the volume of all pores of larger radii than the median radius is equal to the volume of all pores of radii smaller than the median. It must be emphasized that the median radius (or diameter) is only for the interfiber pores; the median radius for all the openings in the fabric may be somewhat higher.

It has long been recognized that the addition of

TABLE III. EFFECT OF MOISTURE ON INTERFIBER PORE SIZE AND VOLUME

Fabric no.	Condition	Interfiber pore volume (cc./g.)	Median diameter of interfiber pores (μ)	Air permeability of dry fabric†	Hydrostatic permeability of wet fabric	
					Height‡	Flow§
6	2/1 Twill					
	Dry	0.770	13.2	5.83	—	—
	Wet*	0.452	12.2	—	10	>10,000
10	Oxford B					
	Dry	0.477	10.2	1.58	—	—
	Wet*	0.328	7.2	—	54	801
11	Oxford C					
	Dry	0.386	8.0	0.80	—	—
	Wet*	0.234	6.4	—	80	65

* Approximately 25% moisture (by weight).
† Air flow in cu. ft./sq. ft./min.
‡ Hydrostatic pressure in cm. of water on the fabric.
§ Permeability in water flow in cc. through a 5½-in. circle in 50 min.

moisture to a cotton fabric swells the fibers and closes, to some extent, the interfiber and interyarn openings. The porosimeter provides an excellent method for investigating this effect, as the results given in Figures 6 and 7 and in Table III demonstrate.

These results indicate that addition of moisture does indeed reduce the interfiber pore volume and pore size. The fiber swelling seems to be as effective with the Group III Oxfords which have been treated with a water-resistant finish (Norane) as with the 2 1 twill which had no such treatment. Experiments at moisture contents much higher than 25% (by weight) give definite indication of liquid water in the interfiber interstices. Thus, with cotton fabrics, maximum swelling has taken place when the fibers have absorbed about 25% moisture. This value has been observed in other investigations as being about the limit of moisture which untreated cotton fibers will take up [2].

The results described indicate that, with additional information, definite quantitative relationships between pore-space distribution and air and water permeabilities of the fabric may possibly be established. That such relationships exist is certainly credible. They are indicated qualitatively by the comparison of air- and water-permeability data given in Table I with the results given in Tables II and III. Fabrics 6, 10, and 11, for example, have high, intermediate, and low (1) air permeabilities, (2) total free space, (3) interfiber pore volumes, (4) median pore diameters, and (5) hydrostatic permeabilities, respectively. Examination of Figure 6 indicates that fabric 11 should be lower in both air and hydrostatic permeabilities than fabric 10, a prediction substantiated by the data of Table I. Similarly, the plot in Figure 8 of air permeability *vs.* space volume indicates a relationship between these variables almost independent of weave construction. Additional investigations are needed to establish more clearly the interplay of these factors in determining fabric properties.

Summary

An improved method for studying the nature of interfiber and interyarn pore spaces in textile fabrics by means of a mercury-pressure porosimeter has been described. Measurements have been reported for 14 fabrics, which include several common weave constructions made of the same yarns and several water-resistant Oxfords of different weights and textures. It has been demonstrated that the porosity data obtained for different weaves show significant differences among these fabrics which help to explain differences in their air permeabilities. It has also been demonstrated that the fibers in water-resistant fabrics swell when exposed to moisture, closing the pores of the fabrics and reducing, to some extent, the passage of water and other wetting liquids. The results obtained suggest that definite relationships exist between pore size and volume on the one hand and air and water permeability on the other.

Acknowledgment

The authors are pleased to acknowledge the assistance of Richard Taylor and Edith Honold in making the porosity determinations, and of Harry A. Mereness for the test data on the original fabrics.

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(Manuscript received June 20, 1949.)

Letters to the Editor

Relationship of Wax Content to Maturity of Cotton*

School of Textiles
The Clemson Agricultural College
Clemson, S. C.
August 12, 1949

To the Editor
Textile Research Journal

Dear Sir:

The maturity of cotton determines to a large extent the general physical properties of the fiber and its ability to be processed—*e.g.*, its spinnability.

A new concept for the determination of maturity based on chemical analysis is proposed, and experimental tests of the method are reported below.

During growth the cotton fiber develops in two distinct phases: (1) the formation of the thin primary wall during the period of elongation, and (2) the subsequent deposition of secondary cell-wall layers inside this preformed primary wall after elongation has stopped. The primary wall is composed of pectins, waxes, and a small amount of cellulose—quite a different chemical composition from that of the secondary wall, which is almost pure cellulose.

It is recognized that the aspects of maturity, from a practical standpoint, are the amount and the structure of cell-wall material deposited in the fiber during the secondary growth. This communication will deal only with the *amount* of cell-wall material.

Definition of Maturity

The conventional technical methods of measuring maturity specify the percentage of fibers considered to be mature on the basis of a definite cell-wall diameter, arbitrarily accepted as a margin between immature and mature fibers. These determinations are made by measuring microscopically the cell-wall thickness after swelling the fiber in alkali, or by use of polarized light, fiber by fiber, or by studying the differential retention of dyestuff in bulk determinations. The above methods have been generally accepted because they can be easily and quickly carried out.

A more explicit and comprehensive indication of maturity would be the quantitative average of cell-wall material per surface area of the fiber instead of the percentage of thick-walled fibers. This overall cell-wall content per surface area will hereinafter be termed "average maturity"—

$$\text{Average maturity} = \frac{\text{amount of cell-wall material}}{\text{perimeter of fiber}}.$$

This average maturity can be determined either by measuring the exact cell-wall cross-sectional areas of individual fibers and comparing this area with the average measured perimeter, or by determining the weight per unit length relative to perimeter. Perimeters may be measured microscopically or by an arealometer.*

A new approach to this problem from a chemical angle has been undertaken and includes some general aspects of maturity as well as the problem of quantitative measurement.

Theoretical Basis

It is theoretically possible to express *directly* the amount of cell-wall material in relation to perimeter in chemical terms by relating the total amount of cell-wall material to special chemical compounds of the primary wall (as indicative of perimeter). Waxes and pectins of the primary wall are suitable substances for reference. The assumption was made that the amount of wax in the primary wall is proportional to the wall surface, and that the total amount does not change throughout the secondary growing period in any given variety.

If these assumptions are valid, the average maturity can be readily expressed by relating the varying amounts of wall substances to the constant quantity of wax in the primary wall as follows:

$$\begin{aligned}\text{Average maturity} &= \frac{\text{cell-wall material}}{\text{perimeter}} \\ &= \frac{\text{cell-wall material}}{\text{primary-wall substance}} \\ &= \frac{\text{cell-wall material}}{\text{wax}} \\ &= \text{a constant} \times \text{reciprocal wax percentage of total fiber.}\end{aligned}$$

* Paper presented at the meeting of The Fiber Society, April 12, 1949.

* Arealometer readings can be used for this purpose only under special conditions, not to be discussed here.

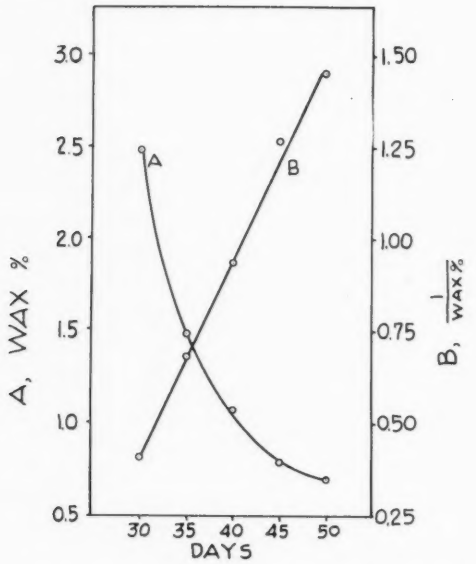

FIG. 1. *Acala 4-2. A—Wax percentage vs. time. B—Reciprocal wax percentage vs. time (in days after flowering).*

Therefore, it follows from the above theoretical consideration that a linear relationship would exist between average maturity and reciprocal wax percentage. In other words, the amount of wax, calculated as a percentage of the total amount of material, will be constantly lowered due to the ever-increasing amount of cell-wall material (cellulose) as the cotton matures.

Experimental Results

In order to test the above conceptions experimentally, it was necessary to obtain material of different known maturities. Specimens of a single variety of cotton picked at increasing biological ages were used for the investigation. If it is assumed that the cell-wall material is deposited at a constant rate during the main period of secondary growth,* it then follows that the amount of material would be directly proportional to the biological age. Therefore, if the reciprocal wax content is indeed a measure of cell-wall content, it has to show a similar linear relationship to the age of the fiber.

*As indicated cytologically by the regular daily growth rings, which are assumed here to contain a constant amount of cellulose.

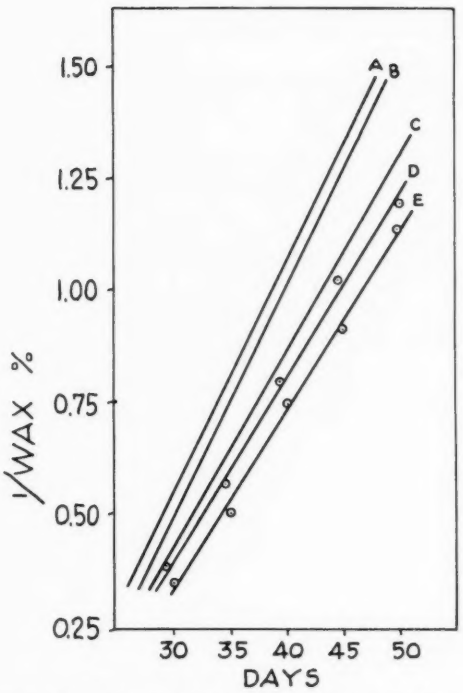

FIG. 2. *Reciprocal wax percentage vs. number of days after flowering in different varieties. A—Half and half. B—Rowden 41B. C—Coker 100 Wilt. D—Variety 200-1-3-3. E—Coker Wilds.*

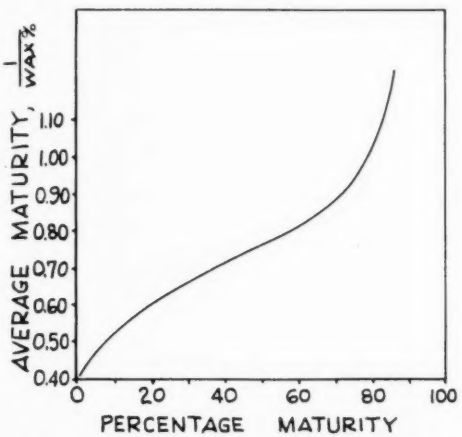

FIG. 3. *Average maturity (as reciprocal wax percentage) vs. percentage maturity (as determined by conventional method: percentage of mature fibers).*

TABLE I. RELATIONSHIP BETWEEN THE "PERCENTAGE" MATURITY* AND "AVERAGE" MATURITY, DETERMINED BY WAX CONTENT

Sample identity			Percentage maturity			
Variety	Growth	Fineness‡ (μg/in.)	Caustic maturity (P.M.A.)	maturity (S.R.R.L.)	Maturity by color (over-all color)	Average maturity: $\left(\frac{100}{\text{Wax percentage}}\right)$
Lockett 140	Chillicothe, Tex.	—	93	90	93	228
Mebane 140	College Station, Tex.	5.4	84	86	86	235
Rowden 41B	Greenville, Tex.	5.5	85	86	84	218
Mechano No. 2	Chillicothe, Tex.	4.6	82	81	82	166
Acala 4-42	College Station, Tex.	3.8	79	78	78	153
Empire WR	Tyler, Tex.	3.7	78	74	73	146
Memphis B/376839†	—	—	—	38	40	92
Hoover B/286404†	El Paso, Tex.	—	—	20	20	65

* Samples and maturity data were furnished by the Southern Regional Research Laboratory. The samples were largely from residues from spinning tests furnished the Southern Laboratory through the kindness of Dr. John W. Wright, Cotton Branch, Production and Marketing Administration, U. S. Department of Agriculture. Maturities were determined at the Southern Laboratory by the conventional caustic soda method, and from the over-all color resulting in differential dyeing (approximately as suggested by Goldthwait, Smith, and Barnett).

† Not varietal designations.

‡ P.M.A. Micronaire fineness determinations.

Curve A of Figure 1 shows the percentage of wax in fibers of increasing biological age, collected every 5 days, starting from exactly 25 days after flowering, at which time the secondary growth has approximately begun. Curve B of Figure 1 represents the *reciprocal* wax percentages also plotted against the age of the fiber, and shows a complete linear relationship, as would be expected from the above theoretical conclusions. (Curve A, therefore, is a hyperbola.) The same linear relationship between reciprocal wax content and age was found in all other varieties investigated.

The direct relationship shown will permit expressing quantitatively the degree of maturity of a sample as compared to a standard, fully mature sample of the same material by the ratio of their wax percentages,* as follows:

$$\text{Average maturity ratio} = \frac{\text{reciprocal wax content in sample tested}}{\text{reciprocal wax content of fully mature sample}} = \frac{\% \text{ of wax in mature sample}}{\% \text{ of wax in sample tested}}$$

In case dimensional values of maturity (absolute cell-wall content) are desired instead of the relative degree of maturity as above, these may be calculated by multiplying the average maturity ratio of the sample tested by the dimensional values actually found in a reference sample such as the fully matured sample.

Results for Different Varieties

Having shown the linear relationship between average maturity and reciprocal wax content for each separate material, it is of value to compare the results for different varieties. Although the reciprocal wax curves for the seven different varieties of Upland cotton investigated were all straight lines (5 are shown in Figure 2), they did not coincide, being practically parallel to each other but showing definite shifts along the age axis.

Some important conclusions may be drawn from these results. Absolute parallelism of the curves would indicate that all different varieties would have the same "basic" * wax content and also the same rate of cell-wall deposition during secondary growth. If either of these above conditions had not been fulfilled, the curves would have different slopes.†

The shift of the curves along the horizontal axis means only that the moment when secondary growth starts in the different varieties is retarded or advanced in relation to time (not over 5 days' shift, as shown in Figure 2).

* It will be necessary to accept as an indication of full maturity an arbitrary cell-wall content because maturity will be always a relative property.

* "Basic" wax designates the amount of wax in the primary wall *per unit* perimeter.

† Parallel curves might also be drawn for a fiber with a different "basic" wax content and a correspondingly different ratio of cell-wall formation in each variety, but the chance of a similar change in these two properties occurring in each variety investigated seems unlikely.

The actual curves obtained for the different varieties being practically parallel indicates an almost identical "basic" wax content and rate of cell-wall deposition. One common *"basic" wax content* is of practical importance because it will permit the calculation of maturity for different varieties by one direct determination, using as reference a single standard value for fully mature cotton. (In case of different "basic" wax contents, different reference standards would have to be introduced.)

Influence of Environmental Conditions

It is not yet known to what extent growth conditions in different years and locations influence the basic wax content; in case such an influence does exist, different standards, of course, would be necessary. Further investigation will decide this question. Any influence of environmental conditions on the rate of cell-wall deposition, on the other hand, will mean actual changes in resulting maturity and as such are the very properties to be determined *by* the method.

Comparison of Average and Percentage Maturity

It can be expected that a close relationship will exist between average maturity, as studied here, and percentage maturity, as specified in the conventional methods of measuring maturity described at the beginning of this letter. This correlation was obtained experimentally by comparing the reciprocal wax content and the percentage maturity for a group of different samples. This group included a series of valuable cottons from the Southern Regional Research Laboratory, Cotton Chemical Finishing Division, for which the percentage maturity had been determined by different methods. Table I (columns 4–6) gives these percentage maturities; the last column gives the average maturity (wax content) obtained in the present investigation. It can be seen that the samples of cotton are ranked by the average maturity values in exactly the same order as by the percentage maturity values. The relationship between the average and percentage maturities is expressed by the curve in Figure 3. It can be seen in Figure 3 that at the middle part of the curve an almost linear relationship exists between the two, but in the lower and higher ranges the curve tends toward the average maturity ordinate. This correlation curve was obtained using a great number of commercial Upland cottons of different variety and origin whose percentages of maturity had already been determined by the conventional method.* By using such experimental correlation curves it would be possible to convert average maturity into percentage maturity and *vice versa*.

Prospects of Developing New Methods for Practical Determination of Average Maturity

The special relationship between wax content and average maturity established in these studies will in itself be of considerable interest in dealing with all kinds of problems of maturity.

The method used in this study may be applied without any alteration as a laboratory method for research purposes where the cell-wall content is required. By the wax determination according to Conrad (as was used here), it is possible to determine the wax content very accurately. In duplicate and triplicate determinations the values differed by only a few percents, and according to private communication from the Bureau of Plant Industries it will be possible to determine the percentage of wax in cotton with an error of less than 1 percent by this method. A disadvantage of the method is that it requires 6 hours' extraction and accurate weighing, and, moreover, that at the higher range of cell-wall content the corresponding decrease of wax percentage becomes smaller and smaller.

Although it is not the intention of this letter to give a perfected method for the determination of maturity, the question arises whether or not on the basis of the results obtained it would be possible to develop a new practical method. It might be possible to adapt the wax method described above to practical use or, alternatively, to employ a determination of the pectins or perhaps other substances, which might require less time. In addition, the possibility of simplification of the methods by chemical or physical means exists.

Very truly yours,

A. N. J. HEYN

* Samples were kindly furnished by Cotton Branch, Production and Marketing Administration, U. S. Dept. of Agriculture.

INDUSTRIAL SECTION

Luster and Cotton*

George S. Buck, Jr.,† and Frank A. McCord‡

Introduction

Much of the research in the textile industry has been directed toward improvements in the usefulness of textile products and lowering of their production costs. Both synthetic and natural fibers have benefited from this emphasis on functional properties and production economy. Too often, however, consumer demand for fabrics is measured simply on the basis of quality and cost, without full recognition of the importance of more indefinable characteristics that constitute "consumer appeal." In many textile applications, particularly in household and apparel uses, more or less intangible fabric characteristics such as hand, texture, luster, and style play as significant roles as such functional qualities as launderability, soil resistance, durability, or warmth.

Luster is one of the major, non-functional appeal characteristics of textiles. It is a quality that defies complete measurement, yet one for which there is a strong demand. It is a quality that is regarded with various degrees of favor by the consumer, depending on its brightness, the fiber with which it is associated, and the specific use of each textile article. Always implying the highest quality in silk and the finest wools and cottons, luster in the early artificial fibers carried a suggestion of inferiority in most functional properties. Today, demand for luster is based largely on its attractive appearance in fabrics, the brighter colors of lustrous textiles, and the contrast with duller fabrics or yarns which permits greater freedom in styling.

For more than 50 years cotton has been mercerized for added luster. Some of the finer, long-staple cottons, when mercerized, approach the desirable subdued luster of natural silk. But satisfaction of the demand for this type of luster in cotton, and for even brighter yarns and fabrics, awaits the development of better and more economical luster finishes. The cotton market is the only fiber market of any importance for such a finish, but the volume of cotton goods in which a higher luster is desirable invites the thoughtful consideration of all who are interested in textile developments.

In luster development, the cotton textile industry presents an almost unique opportunity for research. A very large market is dependent on the answer to a problem, the solution of which seems not only feasible, but to which there are a number of promising approaches. This study, which measures the market demand for luster in cotton goods and reviews the technical background of the subject, has been prepared for persons and organizations who may be interested in the opportunity it sets forth.

Part I—Market Prospects

Basis for Estimates

Cotton yarns and fabrics provide the only important outlet for a textile luster finish because cotton accounts for more than 73% of the total consumption of apparel-type fibers in the United States and because the synthetic fibers and silk have inherent qualities of luster. Usually, a high degree of luster is not desirable in uses where wool is consumed. In addition to offering the largest market for a luster finish, the demand for luster in cotton is stronger

* This is the second in a series of studies dealing with various qualities of cotton being prepared by the National Cotton Council of America. The first, "Crease-Resistance and Cotton," appeared in the April, 1949, issue.

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than in other fibers because luster in cotton has always implied quality, and because added luster would permit wider application of cotton's highly regarded functional properties of launderability, durability, and comfort.

Both expressed and implied preferences of consumers have been taken into consideration in measuring the size of the market for a luster finish on cotton goods. Consumer buying practices studied through retail outlets over a period of 8 years provided much information on textile product preferences. Necessarily, a number of assumptions must be made before the size of any market can be estimated; therefore, the actual market available for a luster finish on cotton will differ from the estimated market as the actual conditions differ from those assumed.

The first assumption is that necessary or desirable functional qualities of cotton in each particular use will not be sacrificed by the addition of luster. This does not mean that no other qualities of cotton fabrics can be changed. In suitcase and jewelry-case linings, for example, launderability and absorbency could be sacrificed because they are not essential qualities in those uses. In clothing, however, the sacrifice of either launderability or absorbency might be a disadvantage outweighing the gain resulting from a luster finish.

Cost or price relationships between cotton and other fibers are assumed to be the same as those prevailing during the summer of 1949. Fluctuations in the prices of synthetic fibers, relative to the price of cotton, will necessarily influence the market estimates somewhat. The development of new synthetics should have little effect on the market estimates, partly because such fibers are slow to reach large volume production, and partly because they compete with synthetic fibers already established. No improvements in the synthetic fibers now available are anticipated which would make any significant change in the estimates, especially since all of the synthetics now available can be produced with a high luster.

The assumption was made that cotton fabrics would be available in any desired degree of luster to adequately fill the demands of each particular market. If ranges of luster in cottons can be produced from dull to the luster of the brightest synthetic there will obviously be a cotton available for each use in which luster is preferred. If only half that amount of luster can be developed, cotton products may still not have sufficient gloss for some markets. In general, however, any significant increase in the luster of cottons will find a strong demand.

Finally, the assumption was made that adequate advertising and merchandising promotions would be available for the full development of the market for a luster finish on cottons. While there is an immediate and recognized demand for higher luster in cottons in many uses, other markets can be fully developed only through consumer education. Luster is a quality that appeals to consumers, but in many cases dull fibers and fabrics have been traditionally used, and it must be demonstrated that the new lustrous cottons are as high in quality as those familiar to the consumer.

Size of the Market

The market for a luster finish on cotton goods is the total volume of textiles in uses in which, knowingly or unknowingly, the consumer desires luster. These uses are now filled partly by cotton and partly by other fibers.

In the markets which cotton holds, some mercerized cotton is used to provide higher luster, but in terms of the total volume of such uses the amount of mercerized cotton is relatively small. The cost of the mercerizing process, together with limitations on the amount of luster which can be achieved from mercerizing, has restricted a fuller utilization of this process. The market for a luster finish in uses now filled by cotton, therefore, can be considered to be the total of the 2,667 million sq. yds. and the 210 million lbs. of yarns listed in Table I.

The synthetics are among the fibers other than cotton which hold parts of the markets listed in Table I in which luster is preferred. In these uses some bright and semi-bright fibers and also some delustered artificial fibers are used. The acceptance of dull synthetics in a particular use, however, has no bearing on the demand for luster in cotton in that use. The dull synthetic may be used simply because it is necessary to imitate the appearance of cotton, while cotton in that use may still be preferred with a higher luster.

The degree of luster desired in cotton varies with the use. Items such as ski suits, bathing suits, and

TABLE I. ESTIMATED ANNUAL POTENTIAL MARKET FOR LUSTER FINISHES ON FABRICS AND YARNS *

Use	Estimated total consumption of cotton materials in uses in which luster is desirable† 1,000 sq. yds.	1,000 lb.	Estimated total consumption of materials other than cotton in uses in which luster is desirable 1,000 sq. yds.	1,000 lb.	Estimated total consumption of all materials in uses in which luster is desirable‡ 1,000 sq. yds.	1,000 lb.
Men's, Youths', and Boys' Apparel						
Coats and jackets						
Separate coats	2,370		12,940		15,310	
Coat and jacket linings (all types except blanket or sheep-lined)	6,830		70,300		77,130	
Gloves, dress	220		5,680		5,900	
Handerkerchiefs	22,500		3,000		25,500	
Hosiery						
Dress and semi-dress		11,670		12,130		23,800
Slack socks		11,190		9,950		21,140
Pajamas and nightshirts	100,000		4,000		104,000	
Rainwear	5,700		370		6,070	
Shirts						
Dress	355,000		14,000		369,000	
Polo, tennis, and basque		48,240		2,540		50,780
Sport	72,000		70,000		142,000	
Suits						
Dress	6,340		120,630		126,970	
Linings	0		26,880		26,880	
Sweaters		870		16,550		17,420
Ties	240		23,760		24,000	
Trousers, dress and sport	22,000		102,000		124,000	
Underwear						
Athletic shirts		20,350		190		20,540
Shirts and drawers, woven	9,400		50		9,450	
Shorts, woven	88,830		220		89,050	
Shorts, knit		6,180		0		6,180
Washable service apparel	31,000		0		31,000	
Total	722,430	98,500	453,830	41,360	1,176,260	139,860
Women's, Misses', and Juniors' Apparel						
Aprons and uniforms						
Aprons	21,800		5,110		26,910	
Uniforms	27,700		700		28,400	
Bathrobes	3,920		6,560		10,480	
Blouses, waists, and shirts	17,000		104,000		121,000	
Coats and jackets	13,270		106,120		119,390	
Coat and jacket linings	3,100		99,800		102,900	
Dresses						
House	147,000		52,000		199,000	
Street	39,000		315,000		354,000	
Foundation garments						
Brassieres and bandeaux	19,100		23,300		42,400	
Corsets, girdles, and belts	7,400		9,100		16,500	
Gloves, dress and semi-dress	1,300	1,850	1,800	2,000	3,100	3,850

* Estimates based on 1947 production of apparel and household and industrial items.

† The items in which luster is important were taken from a list of uses which accounted for approximately 85% of the total annual consumption of cotton during the period 1939–41. While there are no available tabulations to show the consumption of cotton in hundreds of smaller uses which represent the additional 15% to 20% of consumption, it is reasonable to assume that luster finishes are desirable in many of these small uses. Furthermore, a luster finish may be desirable in small segments of some of the larger markets not included in this tabulation, but enough statistical information is not available to permit breakdowns to show such markets. For example, surveys by a manufacturer of work clothing indicate that consumers desire luster in matching sets of work trousers and shirts and that they are willing to pay higher price to obtain garments with luster. This segment of the work clothing market has not been included, however, because of inadequate statistical data on the quantity of fabrics consumed in matching trouser-and-shirt sets.

‡ Total consumption of fabric and yarn in uses which are important market outlets for cotton.

TABLE I. (*Continued*)

Use	Estimated total consumption of cotton materials in uses in which luster is desirable† 1,000 sq. yds.	1,000 lb.	Estimated total consumption of materials other than cotton in uses in which luster is desirable 1,000 sq. yds.	1,000 lb.	Estimated total consumption of all materials in uses in which luster is desirable‡ 1,000 sq. yds.	1,000 lb.
Women's, Misses', and Juniors' Apparel (Continued)						
Handkerchiefs	9,200		500		9,700	
Hosiery						
Full-fashioned		400		61,100		61,500
Seamless		4,830		10,460		15,290
Anklets		7,080		1,250		8,330
Housecoats	1,990		400		2,390	
Negligees	117		4,290		4,407	
Pajamas, bedjackets, and nightgowns	83,000		62,000		145,000	
Rainwear	2,500		7,300		9,800	
Skirts	4,700		61,100		65,800	
Sportswear						
Bathing suits	2,100	0	2,900	700	5,000	700
Slack suits	200		4,000		4,200	
Slacks	4,000		12,000		16,000	
Suits and ensembles	1,700		60,000		61,700	
Suit linings			24,400		24,400	
Sweaters and jerseys				7,900		7,900
Underwear						
Panties, drawers, bloomers	0		1,140		1,140	
Panties, vests, and bloomers		11,300		34,540		45,840
Slips and petticoats	18,000	900	172,000	5,460	190,000	6,360
Washable service apparel	3,310		30		3,340	
Total	431,407	26,360	1,135,550	123,410	1,566,957	119,770
Children's and Infants' Apparel						
Coats and jackets	1,930		24,470		26,400	
Coat and jacket linings	12,440		8,300		20,740	
Dresses	64,000		16,000		80,000	
Hosiery—Anklets		5,400		290		5,690
—Other		6,310		1,580		7,890
Nightwear	22,830	13,360	80	2,360	22,910	15,720
Playsuits	16,000		500		16,500	
Suits and skirts						
Suits (except ski, snow; including wash)	11,500		1,700		13,200	
Skirts	1,140		4,510		5,650	
Linings	2,200		2,000		4,200	
Underwear—Panties, drawers, and bloomers		4,120		1,450		5,570
—Slips and petticoats	6,930		2,920		9,850	
—Waist suits and wrappers		350		90		440
Total	138,970	29,540	60,480	5,770	199,450	35,310
Household Uses						
Bedspreads	81,000		15,000		96,000	
Bed ticking	96,730		0		96,730	
Blankets and blanketing	80,500		153,200		233,700	
Curtains, drapes, and upholstery	284,000		153,000		437,000	
Pillowcases	89,000		400		89,400	
Rugs and bath mats—Bath mats and sets		13,000		0		13,000
—Rugs and carpets		20,000		201,630		221,630
Sheets	545,000		3,600		548,600	
Tablecloths and napkins	62,000		15,000		77,000	
Thread for domestic use		17,700		930		18,630
Towels, huck and damask	25,800		0		25,800	
Total	1,264,030	50,700	340,200	202,560	1,604,230	253,260

TABLE I. (*Continued*)

Use	Estimated total consumption of cotton materials in uses in which luster is desirable† 1,000 sq. yds.	1,000 lb.	Estimated total consumption of materials other than cotton in uses in which luster is desirable 1,000 sq. yds.	1,000 lb.	Estimated total consumption of all materials in uses in which luster is desirable‡ 1,000 sq. yds.	1,000 lb.
Industrial Uses						
Casket linings	37,250		86,920		124,170	
Flags	2,250		750		3,000	
Luggage linings	420		2,380		2,800	
Shoes—Laces		4,700		310		5,010
—Linings	66,160		33,840		100,000	
Umbrellas	4,000		12,000		16,000	
Woven labels		240		200		440
Total	110,080	4,940	135,890	510	245,970	5,450
GRAND TOTAL (sq. yds.)	2,666,917		2,125,950		4,792,867	
(lb.)		210,040		373,610		583,650

snow suits are often preferred with a high luster or sheen. Men's dress shirts, handkerchiefs, and similar items are in greatest demand with a subdued luster. Even in a particular use, different degrees of luster may be desirable. For example, some men would like shirts with the luster of silk if they could be assured of cotton's qualities; other men would resist any change from the traditional dull or slightly lustrous shirts to which they have been accustomed.

Tradition is an important influence in men's apparel uses, where changes in buying habits occur slowly. In women's apparel markets, well-developed preferences for the dressy appearance of lustrous textiles are already apparent. Style trends can quickly develop the latent desire for luster in other women's apparel uses. In all of these textile uses, luster will be accepted more readily with cotton than with other fibers because of the strong preference for cotton's functional qualities.

From Table I it is apparent that the application of luster finish to cotton would permit the wider use of cotton in markets now held by other fibers. These uses total some 2,125,950,000 sq. yds. of fabric annually and 373,610,000 lbs. of yarn. In many cases luster is not the only factor responsible for the hold which other fibers have on these markets, but the total of nearly 5,000,000,000 yds. of fabric and almost 600,000,000 lbs. of yarn (estimated consumption of all materials in which luster is desirable) must still be recognized as the maximum potential for a luster finish on cotton materials.

The development of a high luster in cottons will result in the immediate replacement of other fibers by cotton in some applications. In damasks, for example, which are used for napkins and tablecloths, drapery, and upholstery, a bright synthetic fiber is frequently used as either warp or filling so that lustrous floats can be formed that will produce the damask designs. The use of synthetic yarns generally lowers the functional qualities of these fabrics, sacrificing launderability, durability, and dimensional stability. Such uses would constitute strong, immediate markets for high-lustered cotton yarns.

In other cases, increases in the size of the market for high-luster cottons depend on added luster and on one or more other quality changes in cottons. In suit linings, the important qualities are the functional quality of slipperiness and the appeal quality of luster. High luster would make cotton more popular in suit linings than at present, but full expansion into this market would be limited unless the quality of slipperiness were also added.

Influence of Quality and Price

A—Quality. It is almost axiomatic that any mechanical or chemical processing directed toward modification of a specific textile property will also modify in some manner other properties. A corollary of this is that any change in the characteristics of a textile fabric will influence its acceptability in at least some applications.

TABLE II. ESTIMATED POTENTIAL MARKET FOR LUSTER FINISHES ON COTTON FABRICS AND YARNS, AT FOUR ASSUMED COST LEVELS FOR APPLYING LUSTER FINISHES *

Use	1,000 units	Potential market for luster finishes on cotton fabrics and yarns if unit cost of luster finish is: No increase	1½¢	5¢	10¢
Men's, Youths', and Boys' Apparel					
Coats and jackets—Separate coats	sq. yds.	2,370	2,370	2,000	1,500
Linings (except blanket and sheep-lined)	sq. yds.	6,830	6,830	6,000	4,000
Gloves, dress	sq. yds.	220	220	200	150
Handkerchiefs	sq. yds.	22,500	22,500	15,000	7,500
Hosiery—Dress and semi-dress	lb.	11,670	11,670	11,670	11,670
—Slack socks	lb.	11,190	11,190	10,000	8,500
Pajamas and nightshirts	sq. yds.	100,000	75,000	30,000	12,000
Rainwear	sq. yds.	5,700	5,000	2,500	1,500
Shirts—Dress	sq. yds.	355,000	200,000	100,000	50,000
—Polo, tennis, and basque	lb.	48,240	35,000	20,000	10,000
—Sport	sq. yds.	72,000	65,000	50,000	35,000
Suits—Dress	sq. yds.	6,340	6,340	6,000	5,000
—Linings	sq. yds.	0	0	0	0
Sweaters	lb.	870	870	800	700
Ties	sq. yds.	240	240	240	240
Trousers—Dress and sport	sq. yds.	22,000	20,000	15,000	10,000
Underwear—Athletic shirts	lb.	20,350	18,000	15,000	11,500
—Shirts and drawers	sq. yds.	9,400	8,000	7,000	6,000
—Shorts, woven	sq. yds.	88,830	70,000	50,000	30,000
—Shorts, knit	lb.	6,180	6,180	5,000	4,000
Washable service apparel	sq. yds.	31,000	25,000	15,000	6,000
Total (sq. yds.)		722,430	506,500	298,940	168,890
(lb.)		98,500	82,910	62,470	46,370
Women's, Misses', and Juniors' Apparel					
Aprons and uniforms—Aprons	sq. yds.	21,800	20,000	15,000	10,000
—Uniforms	sq. yds.	27,700	25,000	20,000	18,000
Bathrobes	sq. yds.	3,920	3,920	3,750	3,000
Blouses	sq. yds.	17,000	17,000	17,000	15,000
Coats and jackets	sq. yds.	13,270	13,000	10,000	7,500
Coat and jacket linings	sq. yds.	3,100	3,100	3,100	3,100
Dresses—House	sq. yds.	147,000	120,000	75,000	40,000
—Street	sq. yds.	39,000	39,000	39,000	35,000
Foundation garments—Brassieres and bandeaux	sq. yds.	19,100	19,100	19,000	18,000
—Corsets, girdles, and belts	sq. yds.	7,400	7,400	7,400	7,000
Gloves, dress and semi-dress—Woven	sq. yds.	1,300	1,300	1,300	1,300
—Knit	lb.	1,850	1,850	1,850	1,850
Handkerchiefs	sq. yds.	9,200	9,200	9,000	8,000
Hosiery—Full-fashioned	lb.	400	400	400	400
—Seamless	lb.	4,830	4,830	4,800	4,500
—Anklets	lb.	7,080	7,000	6,000	5,000
Housecoats	sq. yds.	1,990	1,800	1,500	1,000
Negligees	sq. yds.	117	117	117	117
Pajamas, bedjackets, and nightgowns	sq. yds.	83,000	70,000	60,000	40,000
Rainwear	sq. yds.	2,500	2,500	2,500	2,500
Skirts	sq. yds.	4,700	4,700	4,500	4,000
Sportswear—Bathing suits—Woven	sq. yds.	2,100	2,000	1,500	750
—Knit	lb.	0	0	0	0
—Slack suits	sq. yds.	200	200	200	200
—Slacks	sq. yds.	4,000	4,000	4,000	4,000
Suits and ensembles	sq. yds.	1,700	1,700	1,500	1,000
Suit linings	sq. yds.	0	0	0	0

* Estimates based on opinions, formed over an 8-year period of continuing studies and evaluations of cotton's competitive position by uses, on the importance of luster treatments for each use in relation to competing materials, consumer demand, and prices. The estimates should be considered as an indication of the approximate quantity of cotton materials on which a luster finish is desirable at costs shown. Under no condition, should the estimates be considered as a prediction of the quantity of cotton materials which will be finished with a luster treatment at prices shown. Other variable factors, such as influence of luster finish on absorbency, may largely determine the quantity of finished goods irrespective of prices.

TABLE II. (*Continued*)

Use	1,000 units	Potential market for luster finishes on cotton fabrics and yarns if unit cost of luster finish is: No increase	1½¢	5¢	10¢
Women's, Misses', and Juniors' Apparel (Continued)					
Sweaters and jerseys	lb.	0	0	0	0
Underwear—Panties, drawers, bloomers—Woven	sq. yds.	0	0	0	0
—Panties, vests, bloomers—Knit	lb.	11,300	11,300	11,000	10,000
Slips and petticoats—Knit	lb.	900	900	800	700
—Woven	sq. yds.	18,000	18,000	16,500	15,000
Washable service apparel	sq. yds.	3,310	3,000	1,800	1,200
Total (sq. yds.)		431,407	386,037	313,667	235,667
(lb.)		26,360	26,280	24,850	22,450
Children's and Infants' Apparel					
Coats and jackets	sq. yds.	1,930	1,000	700	200
Coat and jacket linings	sq. yds.	12,440	10,000	8,000	7,500
Dresses	sq. yds.	64,000	50,000	25,000	10,000
Hosiery—Anklets	lb.	5,400	5,000	3,500	2,500
—Other	lb.	6,310	6,000	4,000	3,000
Nightwear—Knit	lb.	13,360	8,000	3,000	1,000
—Woven	sq. yds.	22,830	15,000	7,500	3,500
Playsuits	sq. yds.	16,000	12,000	6,000	2,500
Suits and skirts—Suits	sq. yds.	11,500	10,000	7,500	5,000
—Skirts	sq. yds.	1,140	1,000	800	600
—Linings	sq. yds.	2,200	2,000	1,500	1,000
Underwear—Panties, drawers, and bloomers	lb.	4,120	4,000	3,000	2,000
—Slips and petticoats	sq. yds.	6,930	6,000	5,000	3,000
—Waist suits and wrappers	lb.	350	300	200	100
Total (sq. yds.)		138,970	107,000	62,000	33,300
(lb.)		29,540	23,300	13,700	8,600
Household Uses					
Bedspreads	sq. yds.	81,000	75,000	45,000	20,000
Bed ticking	sq. yds.	96,730	40,000	20,000	10,000
Blankets and blanketing	sq. yds.	80,500	70,000	50,000	40,000
Curtains, drapery, upholstery, and tapestry	sq. yds.	284,000	225,000	175,000	100,000
Pillowcases	sq. yds.	89,000	65,000	35,000	10,000
Rugs—Bath mats and sets	lb.	13,000	10,000	7,500	2,500
—Rugs and carpets	lb.	20,000	12,500	9,000	5,000
Sheets	sq. yds.	545,000	250,000	150,000	50,000
Tablecloths and napkins	sq. yds.	62,000	50,000	30,000	18,000
Thread for domestic use	lb.	17,700	17,000	15,000	12,000
Towels, huck and damask	sq. yds.	25,800	22,500	20,000	15,000
Total (sq. yds.)		1,264,030	797,500	525,000	263,000
(lb.)		50,700	39,500	31,500	19,500
Industrial Uses					
Casket linings	sq. yds.	37,250	35,000	20,000	15,000
Flags	sq. yds.	2,250	2,000	1,500	1,000
Luggage	sq. yds.	420	400	200	100
Shoes—Laces	lb.	4,700	4,000	3,000	2,000
—Linings	sq. yds.	66,160	60,000	40,000	20,000
Umbrellas	sq. yds.	4,000	4,000	3,000	2,500
Woven labels	lb.	240	240	200	100
Total (sq. yds.)		110,080	101,400	64,700	38,600
(lb.)		4,940	4,240	3,200	2,100
GRAND TOTAL (sq. yds.)		2,666,917	1,898,437	1,264,307	739,457
(lb.)		210,040	176,230	135,720	99,020

TABLE III. ESTIMATED POTENTIAL INCREASE FOR COTTON FABRICS AND YARNS, RESULTING FROM APPLICATION OF LUSTER FINISHES, AT FOUR ASSUMED COST LEVELS FOR APPLYING THE FINISH *

Use	1,000 units	Increase in potential market if unit cost of luster finish is: No increase	1½¢	5¢	10¢
Men's, Youths', and Boys' Apparel					
Coats and jackets—Separate coats	sq. yds.	12,940	12,940	12,000	10,000
Linings (except blanket and sheep-lined)	sq. yds.	70,300	70,000	50,000	25,000
Gloves, dress	sq. yds.	5,680	5,000	3,000	2,000
Handkerchiefs	sq. yds.	3,000	3,000	2,500	2,000
Hosiery—Dress and semi-dress	lb.	12,130	12,130	12,130	12,130
—Slack socks	lb.	9,950	9,950	9,000	8,500
Pajamas and nightshirts	sq. yds.	4,000	4,000	3,000	2,000
Rainwear	sq. yds.	730	300	200	100
Shirts—Dress	sq. yds.	14,000	12,000	9,000	5,000
—Polo, tennis, and basque	lb.	2,540	2,500	2,000	500
—Sport	sq. yds.	70,000	70,000	65,000	50,000
Suits—Dress	sq. yds.	120,630	120,000	100,000	50,000
—Linings	sq. yds.	26,880	26,800	25,000	18,000
Sweaters	lb.	16,550	16,500	15,000	12,500
Ties	sq. yds.	23,760	23,700	20,000	15,000
Trousers, dress and sport	sq. yds.	102,000	100,000	75,000	40,000
Underwear—Athletic shirts	lb.	190	190	150	100
—Shirts and drawers	sq. yds.	50	50	25	0
—Shorts, woven	sq. yds.	220	220	200	100
—Shorts, knit	lb.	0	0	0	0
Washable service apparel	sq. yds.	0	0	0	0
Total (sq. yds.)		453,830	448,010	364,925	219,200
(lb.)		41,360	41,270	38,280	33,730
Women's, Misses', and Juniors' Apparel					
Aprons and uniforms—Aprons	sq. yds.	5,110	5,000	2,500	1,000
—Uniforms	sq. yds.	700	700	600	500
Bathrobes	sq. yds.	6,560	6,560	6,000	5,000
Blouses	sq. yds.	104,000	104,000	100,000	80,000
Coats and jackets	sq. yds.	106,120	106,000	100,000	90,000
Coat and jacket linings	sq. yds.	99,800	99,000	80,000	60,000
Dresses—House	sq. yds.	52,000	52,000	45,000	30,000
—Street	sq. yds.	315,000	315,000	300,000	250,000
Foundation garments—Brassieres and bandeaux	sq. yds.	23,300	23,000	20,000	18,000
—Corsets, girdles, and belts	sq. yds.	9,100	9,000	8,000	6,500
Gloves—Woven	sq. yds.	1,800	1,800	1,500	750
—Knit	lb.	2,000	2,000	1,500	750
Handkerchiefs	sq. yds.	500	500	400	300
Hosiery—Full-fashioned	lb.	61,100	61,000	61,000	50,000
—Seamless	lb.	10,460	10,000	8,000	5,000
—Anklets	lb.	1,250	1,200	1,000	800
Housecoats	sq. yds.	400	400	200	100
Negligees	sq. yds.	4,290	4,200	4,000	3,000
Pajamas, bedjackets, and nightgowns	sq. yds.	62,000	62,000	50,000	40,000
Rainwear	sq. yds.	7,300	7,000	5,000	3,000
Skirts	sq. yds.	61,100	60,000	40,000	25,000
Sportswear—Bathing suits—Woven	sq. yds.	2,900	2,500	2,000	1,000
—Knit	lb.	700	700	600	500
—Slack suits	sq. yds.	4,000	4,000	3,000	2,000
—Slacks	sq. yds.	12,000	12,000	9,000	6,000
Suits and ensembles	sq. yds.	60,000	60,000	50,000	35,000
Suit linings	sq. yds.	24,400	24,000	20,000	14,000

* Estimates are based on opinions, formed over an 8-year period of continuing studies and evaluations of cotton's competitive position by end uses, on the importance of luster finishes for each use in relation to competing materials, consumer demands, and price. The estimates indicate the extent to which the per unit cost of cotton fabrics or yarns could be increased through application of luster finishes without placing cotton at a price disadvantage relative to competing materials. The estimates are subject to the conditions outlined in the text of the article, and should not be used as a prediction of the market for any particular luster finish.

TABLE III. (*Continued*)

Use	1,000 units	Increase in potential market if unit cost of luster finish is: No increase	1½¢	5¢	10¢
Women's, Misses', and Juniors' Apparel (Continued)					
Sweaters and jerseys	lb.	7,900	7,500	7,000	6,000
Underwear—Panties, drawers, bloomers—Woven	sq. yds.	1,140	1,100	1,000	750
—Panties, vests, and bloomers—Knit	lb.	34,540	34,000	30,000	20,000
—Slips and petticoats—Knit	lb.	5,460	5,000	4,000	2,500
—Woven	sq. yds.	172,000	170,000	125,000	75,000
Washable service apparel	sq. yds.	30	30	30	0
Total (sq. yds.)		1,135,550	1,129,790	973,230	746,900
(lb.)		123,410	121,400	113,100	85,550
Children's and Infants' Apparel					
Coats and jackets	sq. yds.	24,470	24,000	18,000	14,000
Coat and jacket linings	sq. yds.	8,300	8,000	7,000	5,000
Dresses	sq. yds.	16,000	16,000	14,000	10,000
Hosiery—Anklets	lb.	290	290	250	200
—Other	lb.	1,580	1,500	1,250	1,000
Nightwear—Knit	lb.	2,360	2,300	1,250	900
—Woven	sq. yds.	80	80	60	30
Playsuits	sq. yds.	500	400	100	50
Suits and skirts—Suits	sq. yds.	1,700	1,500	1,200	800
—Skirts	sq. yds.	4,510	4,000	2,750	1,800
—Linings	sq. yds.	2,000	1,800	1,500	1,000
Underwear—Panties, drawers, and bloomers	lb.	1,450	1,400	1,000	700
—Slips and petticoats	sq. yds.	2,920	2,900	2,250	1,700
—Waist suits and wrappers	lb.	90	90	50	25
Total (sq. yds.)		60,480	58,680	46,860	34,380
(lb.)		5,770	5,580	3,800	2,825
Household Uses					
Bedspreads	sq. yds.	15,000	15,000	10,000	5,000
Bed ticking	sq. yds.	0	0	0	0
Blankets and blanketing	sq. yds.	153,200	150,000	100,000	75,000
Curtains, drapery, upholstery, tapestry	sq. yds.	153,300	153,000	120,000	100,000
Pillowcases	sq. yds.	400	400	400	300
Rugs—Bath mats and sets	lb.	0	0	0	0
—Rugs and carpets	lb.	201,630	201,600	175,000	100,000
Sheets	sq. yds.	3,600	3,600	3,600	3,000
Tablecloths and napkins	sq. yds.	15,000	15,000	12,500	10,000
Thread for domestic use	lb.	930	900	800	700
Towels, huck and damask	sq. yds.	0	0	0	0
Total (sq. yds.)		340,500	337,000	246,500	193,300
(lb.)		202,560	202,500	175,800	100,700
Industrial Uses					
Casket linings	sq. yds.	86,920	86,000	60,000	35,000
Flags	sq. yds.	750	750	700	500
Luggage	sq. yds.	2,380	2,300	2,000	1,500
Shoes—Laces	lb.	310	275	200	150
—Linings	sq. yds.	33,840	33,000	20,000	15,000
Umbrellas	sq. yds.	12,000	12,000	9,000	6,000
Woven labels	lb.	200	200	100	50
Total (sq. yds.)		135,890	134,050	91,700	58,000
(lb.)		510	475	300	200
GRAND TOTAL (sq. yds.)		2,126,250	2,107,530	1,723,215	1,251,780
(lb.)		373,610	371,225	331,280	223,005

The chances are fairly remote that a finish could be developed for cotton that would significantly increase its luster and at the same time leave all other properties of the fiber and fabric unaffected. Changes in other properties that accompany the development of luster are not necessarily injurious to the fabric, but may actually prove beneficial. Mercerization, for example, not only adds luster but also increases the strength of yarns and makes them more absorptive to water, dyes, and resins. Luster finishes could improve soil resistance, drape, or other qualities of cotton fabrics and thus expand the potential market beyond the volume indicated in Table I. On the other hand, changes in fabric qualities that might accompany the development of luster could be harmful enough in certain uses to seriously reduce the potential market for a particular finish.

In cotton goods, the usefulness of a luster finish would be sharply limited if it were not of the durable type. Furthermore, reductions in launderability, durability, or absorbency would decrease the usefulness of a luster finish in many of cotton's present markets. Changes in other properties would affect specialized applications and might in some cases entirely overcome the advantages of higher luster.

B—Price. The influence of price on the potential market for luster finish on cotton is indicated in Table II. It will be noted that some markets are extremely sensitive to any increase in cost, while others are estimated to carry nearly the same demand at 10¢ per yard increased cost as at no increased cost per yard. Data in Table II provide a partial measure of the strength of the consumer demand for luster in the uses listed. The table gives no clue to the degree of luster desired, nor does it give a warning as to what other qualities must not be sacrificed in each use. Table II simply measures the demand in terms of cost of the luster finish with the assumption that the degree of luster will be whatever is desired and that all other properties of the cotton fabric or yarn will remain unchanged.

Table III, like Table II, shows only the influence of price—in this case, the effect of price on potential increases in the use of cotton at the expense of other fibers. In many cases qualities other than luster may be so important that only a fraction of the potential markets shown at the four cost levels can be realized. In some cases, where luster may be the principal reason for use of a fiber other than cotton, a large proportion of the potential market increase shown may be gained by cotton with a suitable luster finish.

The use of Tables I, II, and III for estimating the demand for luster in specific markets and for showing the influence of price can best be illustrated by several examples. The samples cited have been selected to illustrate different types of luster markets, and it should not be assumed that these uses represent a more important demand than others not thus fully described.

Men's Dress and Semi-Dress Hosiery

Table I lists 11,670,000 lbs. of cotton in this use, with 12,130,000 lbs. of other fibers being consumed in the same use. Table II shows that the cost of the luster finish on cotton yarns does not decrease the demand for higher luster in cotton for this use even up to 10¢ increase per pound. A luster equivalent to that of present mercerized cottons will be sufficient for a part of this market, but higher luster in the body yarns of socks is desired by many consumers for a dressy appearance. Rayon holds about half of the volume of competing fibers in this use, principally on the basis of high luster, with sheerness and other qualities being lesser considerations. In Table III, the total of 12,000,000 lbs. of competing fibers used in men's dress and semi-dress hosiery indicates a potential market into which cotton might expand, thus enlarging the demand for luster in cotton beyond the 11,000,000 lbs. of cotton now used. Assuming that a finish were developed giving cotton any desirable degree of luster, cotton could be expected to replace most of the rayon in this market. Inroads on the remainder of this market which is held by other fibers such as wool and nylon would be much smaller since these fibers hold their positions largely on the basis of qualities other than luster.

Women's Full-Fashioned Hosiery

This market contrasts sharply with the market for men's dress hosiery discussed above. Table I lists 400,000 lbs. of cotton yarns and 61,100,000 lbs. of yarns of competing fibers. Table II shows the market for higher cotton luster in this use to be as large at 10¢ per pound increased cost as at no increased cost. Therefore, the demand for a luster finish on cotton is strong in this use. Table III lists the total of 61,100,000 lbs. of competing yarns for this use, indicating a potential market into which

more lustrous cottons could expand, and shows this total to have dropped only to 50,000,000 lbs. at 10¢ per pound increased cost. Actually, however, the replacement of other fibers by cotton in this use would be very small, since by far the most important quality is sheerness rather than luster.

Men's Dress Shirts

355,000,000 sq. yds. of cotton are consumed annually in men's dress shirts, and only 14,000,000 sq. yds. of competing materials. Some luster is desirable in the total volume of cotton used for men's dress shirts, but Table II shows that this demand falls off rather sharply as the cost of the finish increases—dropping to 50,000,000 sq. yds. at 10¢ per yard increased cost. Possible expansion in this market by replacement of other fibers is obviously small, being limited to 14,000,000 sq. yds. at no increased cost of finish and dropping to 5,000,000 sq. yds. at 10¢ per yard increase. This potential expansion will actually be considerably less than the 14,000,000 yds. indicated, since part of this market is held by wool on the basis of qualities other than luster.

Sheets

Like the men's dress shirt market, the sheet market of 545,000,000 sq. yds. is a price-sensitive one with little expansion possible by replacement of other fibers. The demand for luster at a 1½¢ per yard added finishing cost has dropped to 250,000,000 yds., but even at 10¢ per yard increase a quality demand is estimated to exist for 50,000,000 yds.

Women's Rainwear

The women's, misses', and juniors' markets *as a whole* offer the strongest potential for a luster finish on cotton. Even at a 10¢ per yard added finishing cost these markets amount to nearly a quarter of a billion yards. The women's rainwear market exemplifies many of these uses, the demand for luster in the 2,500,000 yds. of cotton holding firm even at 10¢ per yard added cost. Furthermore, excellent prospects exist for expansion in the 7,000,000 yds. held by other fibers, largely on the basis of luster.

Curtains, Drapery, Upholstery, Tapestry

This classification represents the largest and strongest *single market* for a luster finish on cotton. Even at 10¢ per yard added cost the demand is estimated at 100,000,000 sq. yds., and at the same cost increase prospects exist for sizable expansions into another 100,000,000 sq. yds. held by competing fibers.

Summary

Uses in which luster is a desirable textile quality total nearly 5,000,000,000 sq. yds. of fabric annually and approximately 600,000,000 lbs. of yarn (Figures 1 and 2). In many uses the demand for luster in cotton is strong, so that even at a cost increase of 10¢ per square yard of fabric and 10¢ per pound of yarn there exists a potential market of about 2,000,000,000 sq. yds. and 300,000,000 lbs. The demand for higher luster in cottons, at 10¢ per yard or pound increased cost and considering only the volume of cotton now used, amounts to about 740,000,000 sq. yds. of fabric and 100,000,000 lbs. of yarn annually (Table II).

The full market for a luster finish on cotton estimated in Figures 1 and 2 can be realized only if: (1) a degree of luster equal to the requirements of each use is realized; (2) the luster finish is durable and not injurious to important yarn and fabric properties in a particular use; and (3) the sales promotion effort required for the development of some markets is obtained. The proportion of the total demand for luster that any finish can satisfy depends therefore on its ability to fulfill these three conditions.

The market for luster, besides being one of the largest and strongest for a finish on cotton, offers a number of unusual incentives for research and development work. A finish that increases luster only moderately will still find a large market, especially if its cost is low. Finishes can be developed for both yarns and fabrics, and in each case the demand is large. In many cases, markets are available immediately, with no advertising or promotional effort necessary. Finally, a great many of the uses are relatively insensitive to cost increases up to 10¢ per square yard and 10¢ per pound of yarn.

Part II—Technical Aspects

Foreword

In the following review of the technical aspects of textile luster an attempt has been made to include the essence of available factual material on the subject and at the same time to condense and simplify

the entire discussion as much as possible. In some cases—mercerizing, for example—it has been necessary to condense to a few paragraphs a subject upon which several volumes have been published. The necessary brevity of treatment of several of the more complicated or controversial points may be overcome by consulting the literature sources appended to each section.

The important point about the subject of textile luster, in so far as cotton is concerned, is that there is still much to be learned which may pave the way for the development of luster finishes of a quality significantly better than those now obtainable. It is hoped that enough material has been provided by this report to stir the interest of scientists and at the same time to enlist the support of executives of the chemical and textile industries.

Nature and Origin of Textile Luster

Luster in textiles is a form of light reflection originating in the fibers that make up th yarn or fabric. Its appeal is essentially sensory and may very well give a somewhat different impression to each observer, although at least certain of its components can be measured objectively. It is a quality as difficult to define as it is to measure, yet one that has been valued by consumers for centuries. Although the almost universal recognition of this textile property makes a difficult, lengthy definition unnecessary, some general observations on the nature of luster may serve to introduce a study of its origin.

"Luster" is one of several terms used to describe the characteristic light reflection of certain materials. "Glitter," "sparkle," "gloss," and "sheen" are among the other terms used, and although each has no doubt a special connotation to different individuals, they are used interchangeably to some extent, and none of the five completely describes the nature of the light sensation. "Glitter" may be used to describe the intense highlights of a diamond, while "sparkle" seems to imply a larger number of lesser reflections. "Gloss" finds most frequent application in the de-

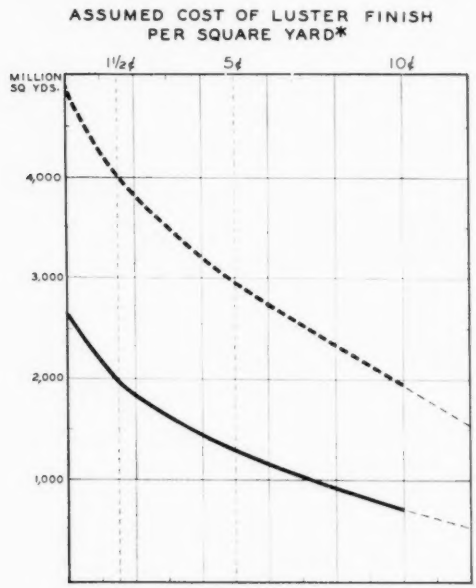

FIG. 1. *Estimated potential market for luster treatments on cotton fabrics (solid line). Estimated total market for fabrics in which luster is important (dotted line). Curves derived from data in Tables II and III. *Cost increase resulting from application of a luster finish.*

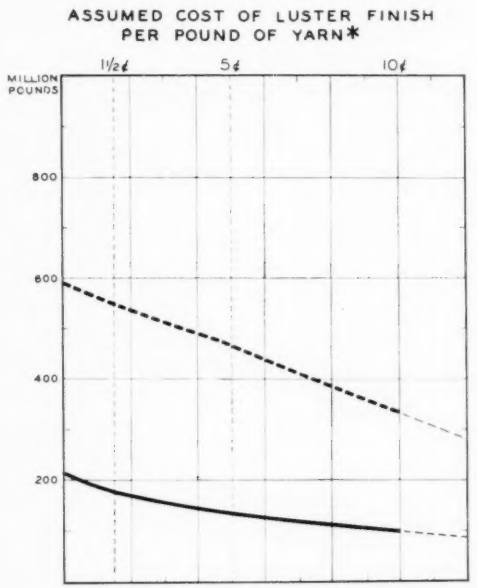

FIG. 2. *Estimated potential market for luster treatments on cotton yarns (solid line). Estimated total market for yarns in which luster is important (dotted line). Curves derived from data in Tables II and III. *Cost increase resulting from application of a luster finish.*

scription of polished surfaces, or more particularly with reference to varnishes, paints, and lacquers. "Sheen" carries some impression of texture, and has been defined as the characteristic light reflection from a nearly matt surface viewed at almost grazing angles.

"Luster" is perhaps somewhat broader in scope than the other four terms. It has been used to describe the light-reflecting properties of gems, glassware, china, and metals, as well as of textiles. As far as textiles are concerned, however, "luster" is the principal term used to describe light-reflecting properties. In textiles, luster is essentially a phenomenon of contrasts between bright or highly reflective areas and duller backgrounds. Movement of the reflective surface, as well as undulations, curves, and folds, accentuates the contrasts between lustrous and matt areas, with shifts in the locality of the lustrous highlights occurring as the position of either the observer, the fabric, or the light source changes. When a fabric is examined for luster, it is customary to hold it so that light falling on it is reflected to the eye from several different angles; if the contrast between brightness and dullness is pleasing, the fabric is said to have desirable luster.

Many factors cause the perception of luster in textiles to be a very complex sensation, involving not only physical, but physiological and psychological considerations as well. However, the following technical discussion will be concerned principally with the physical phenomena of luster, with only necessary reference to physiological and psychological effects. Fortunately, for most purposes an adequate comprehension of the subject can be obtained through the application of the simpler rules of optics in which light is treated as a beam or bundle of essentially parallel rays. The application of a few of the simpler principles of light explain much of the origin of textile luster.

When a beam of light falls on the surface of a material, it may be reflected, it may pass through the material, or it may be absorbed and converted into heat energy. (See Figure 3.) Note that in *B* the direction of the light is changed in passing from one medium (the air) into the second medium. Some combination of these three effects can, and does, take place in many instances.

Since luster is a form of light reflection, case *A* would appear to have the greatest importance, and will therefore be discussed before the complicating factors of *B* and *C* are considered. In *A* (also illustrated in Figure 4) all of the light falling on the surface may be reflected, as from a mirror. This is known as regular or specular reflection. In this case, the angle of incidence *i* of the original ray is equal to the angle of reflection *r*, and both the original and the reflected rays lie in the same plane perpendicular to the reflective surface. This type of reflection reproduces a distinct image of the light source.

The great majority of surfaces, however, lack the polished uniformity of a mirror, and minute irregularities tend to scatter the incident light in all directions. The extreme case of scattered, or diffuse, reflection is shown in *B* (Figure 4), in which the surface appears to be equally well illuminated when viewed from any angle. Such surfaces are called "matt."

The third type of reflection, illustrated in *C* (Figure 4), is a combination of *A* and *B*. Part of the incident light is reflected diffusely, but at the angle of specular reflection the intensity of the reflected light is greatest, and this maximum reflection is known as the "mirror peak." Surfaces such as that illustrated in *C*, which show a mirror peak, represent one type of luster.

The irregularities that cause this deviation from mirror reflection may be very small, such as would occur on a highly polished surface that had been rubbed lightly with an abrasive material. In other cases, the surfaces may be much more irregular, with areas of fairly high reflection occurring as islands of brightness on a matt background. The distinct

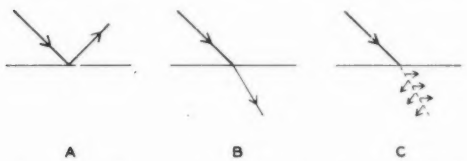

FIG. 3. *Reflection, refraction, and absorption of light, illustrated in A, B, and C, respectively, contribute to the phenomenon of luster.*

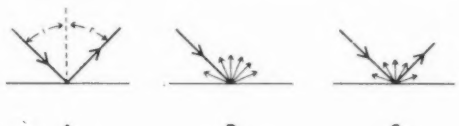

FIG. 4. A—*Specular reflection.* B—*Diffuse reflection.* C—*Diffuse reflection with a mirror or luster peak.*

image that is observed in the case of *A* blurs and disappears as more light is diffusely reflected; in the case of surfaces as irregular as those of textiles, images are never visible.

Textile fibers differ in shape from the flat surfaces discussed above, but the same rules of geometrical optics can be applied to them. A fiber may be considered to be an extremely attenuated cylinder, the simplest case being a cylinder of circular cross section. Figure 5 illustrates light falling on a section of such a cylinder or fiber—across the fiber in *A* and in the direction of the fiber in *B*. It will be noted that in *A* the same intensity of reflection is observed from almost any angle, and that, due to the divergence of the rays, the reflection tends to be weaker than the source, even assuming perfect reflectance. In *B*, however, reflection of all the rays is at the same angle, and a definite mirror peak will be observed at the angle of specular reflection.

The fact that mirror peaks occur predominantly when fibers are viewed in the direction of their axes, thus providing the important contrast between matt appearance and bright reflectance, is one of the primary rules of textile luster. The design of every textile product in which lustrous effects are desired utilizes this principle. The phenomenon can be observed nicely by winding a lustrous yarn around a flat card so that a flat pad of fibers or filaments is obtained. Rotation of this card between the observer and a light source, first around the fiber axes and then across the axes, will show the pronounced contrasts of reflection in the fiber direction.

Since lustrous effects in textiles depend on reflection along the length of a cylinder as illustrated in *B* of Figure 5, it is readily apparent that irregularities in the shape of the fiber cylinder will diffuse or otherwise interrupt the continuity of light reflection. This was found to be true in some of the earliest studies of textile luster. Several workers concluded that the cross-sectional shape of the fiber exerts the most important influence on textile luster, and that surface reflection has more significance than any other type of light reflection.

Figure 6 illustrates some typical fiber cross sections. Cross sections of a bundle of cotton fibers are illustrated in *A*. The irregularity of these sections is obvious. Furthermore, this illustration represents not only a fiber-to-fiber irregularity, but also irregularity within a fiber, since almost any of the shapes shown can be observed at different points along the length of a single fiber. In addition, the fiber is twisted or convoluted, first one way and then the other, up to 75 half-turns per centimeter, so that a further irregularity is introduced.

While the cross sections of the rayon fibers in *B* and *C* of Figure 6 certainly are far from circular, the shape of an individual filament is fairly constant throughout its length, and thus each fiber could be conceived to act as a bundle of smaller cylindrical fibers. Very high luster is a natural property of both of the rayons shown.

The silk fiber cross sections shown in *D* of Figure 6 differ from the majority of textile fibers in that they are triangular in shape rather than curved. The luster of silk is much softer than that of normal rayons, yet greater than that of any other natural fiber.

Even though their shapes differ markedly, all of the synthetic fibers shown in Figure 6 have a high luster. The conclusion that surface reflection is primarily responsible for luster emphasizes the importance of shape and shape continuity as the principal fiber properties contributing to luster. Experimental work backed by mathematical calculations has been presented to show that the ideal cross-sectional shape is that of an ellipse the ratio of major to minor axes of which approaches unity. Thus, flatter, ribbon-like cottons would have less luster than those with rounded shapes. Considerable support was lent to this conclusion by the rounding-out of the shape of cotton fibers during mercerization, as shown in the photomicrographs in Figure 7. Besides making the cotton fiber more nearly round, mercerization removes its convolutions to a considerable extent and thus improves the continuity of shape along the fiber.

The origin of textile luster is evidently more complex than simple specular reflection from fiber surfaces, however, and although the influences of fiber surface and fiber shape cannot be disregarded, other

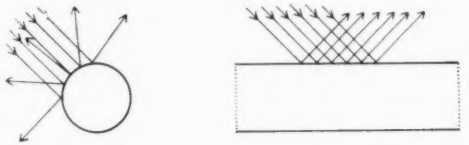

FIG. 5. *Luster is always more apparent in the fiber direction, as in* B, *than across the fiber, as in* A.

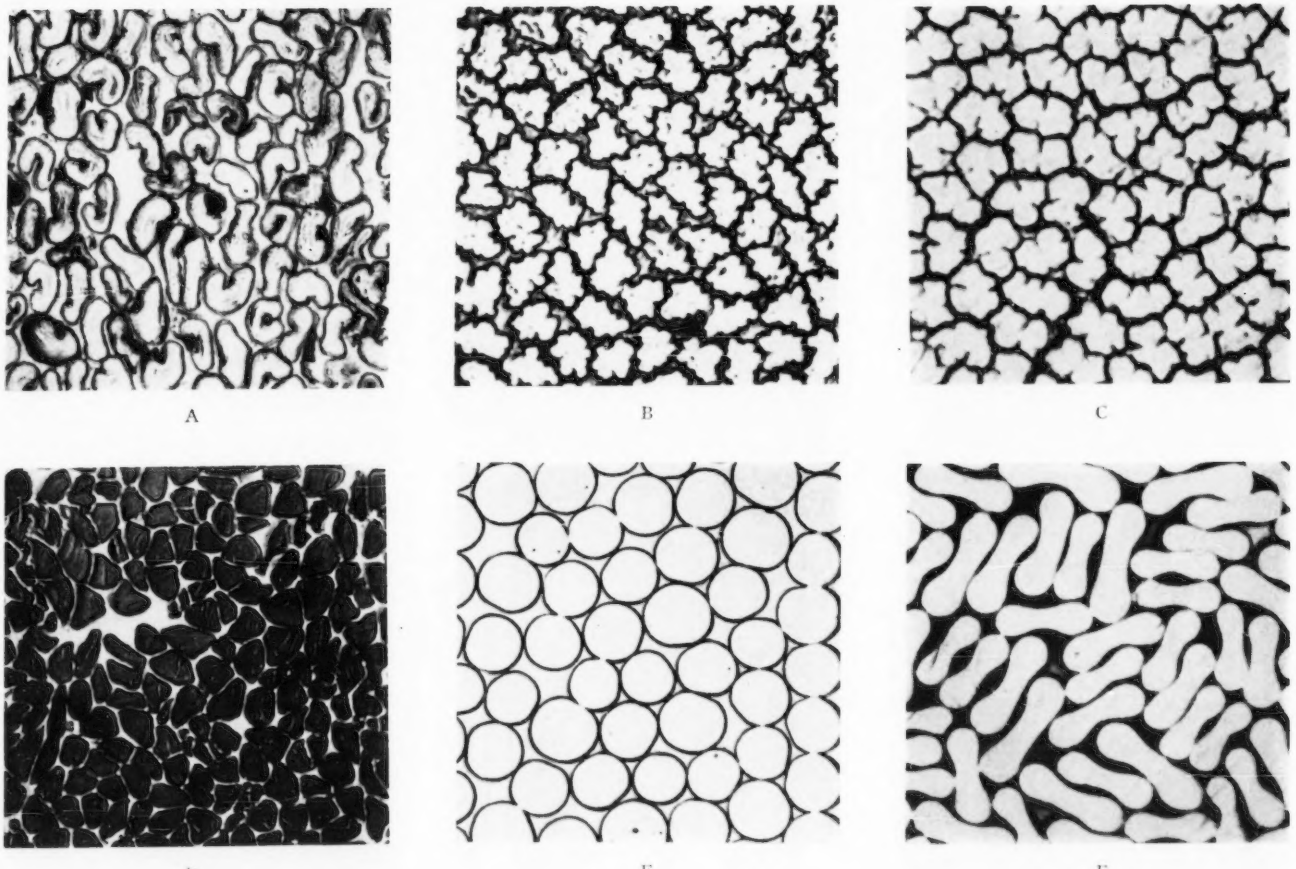

FIG. 6. *Photomicrographs of cross sections of six textile fibers.* A—*Raw cotton fiber (Acala), U.S.D.A. photomicrograph, Bureau of Animal Industry.* B—*Viscose rayon fiber, U.S.D.A. photomicrograph, Southern Regional Research Laboratory.* C—*Acetate rayon fibers, U.S.D.A. photomicrograph, Southern Regional Research Laboratory.* D—*Silk fibers, U.S.D.A. photomicrograph, Bureau of Animal Industry.* E—*Nylon fibers, U.S.D.A. photomicrograph, Southern Regional Research Laboratory.* F—*Vinyon fibers, U.S.D.A. photomicrograph, Southern Regional Research Laboratory.*

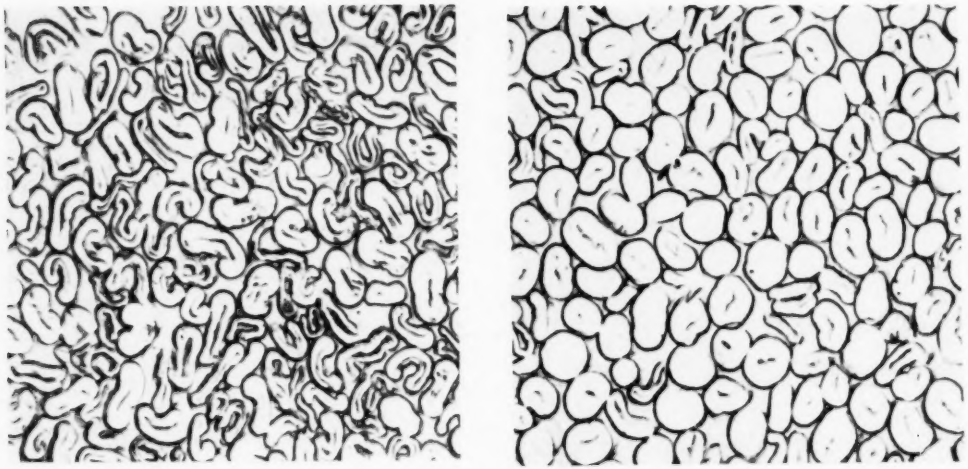

FIG. 7. A (left)—*Cross section of Empire cotton, raw.* B (right)—*Cross section of Empire cotton, mercerized. U.S.D.A. photomicrographs, Southern Regional Research Laboratory.*

and perhaps equally important fiber properties must be considered. The fact that cotton fibers mercerized without tension improve in shape with little or no improvement in luster throws some doubt on the conclusion that shape is all-important. The degree of shape improvement between unmercerized and mercerized-unstretched cotton is much greater than the shape improvement from mercerized-unstretched to mercerized-stretched cotton, yet the development of luster is far more pronounced in the latter case than in the former. Some further question of shape-factor importance, with respect to surface reflection, is raised by the fact that textile fibers are relatively transparent (see Figure 8), so that only a fraction of the incident light is reflected from the surface, the major part passing into or through the fiber. According to Fresnel's law,* only about 4% of the light normally incident on a cotton fiber will be reflected, and even at 60° incidence not over 10% of the incident light is reflected. It is logical, therefore, that example *B* in Figure 3 be studied to determine what happens to the light passing into the fiber.

In *B* of Figure 3 the light ray is shown to be bent or refracted upon entering the second medium. This condition is reproduced in Figure 9, where light is shown falling on a layer of transparent fibers. At each air-fiber surface, a part of the light is reflected and part refracted. It will be noted that much of the light passing through one or more fibers can find its way out again on the top of the layer of fibers, reinforcing the light reflected from the first surface.

Figure 9 is intended to represent the longitudinal sections of perfectly uniform circular cylinders. Naturally, the circular cross section will cause light reflected from the inside of the fiber to emerge fanwise, but the effect will be about as shown in the diagram. Glass fibers are probably the only textile fibers that may nearly duplicate the conditions represented. Glass fibers have a smooth, uniform shape of circular cross section, and the interior is homogeneous or optically isotropic. Even in the case of glass fibers, however, only a portion of the incident light will finally re-emerge to reinforce the light specularly reflected from the surface. Some of the

* Fresnel's law relates the intensity of light reflected from a surface (I_r) to the intensity (I_o) and incident angle (i) of the source light and to the refractive index of the material from which the light is reflected. The relationship can be expressed as follows:

$$I_r = I_o \frac{1}{2}\left[\frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)}\right].$$

The angle of incidence (i) and the angle of reflection (r) are related to the index of refraction (μ) of the material by Snell's law:

$$\text{Refractive index } \mu = \frac{\sin i}{\sin r}.$$

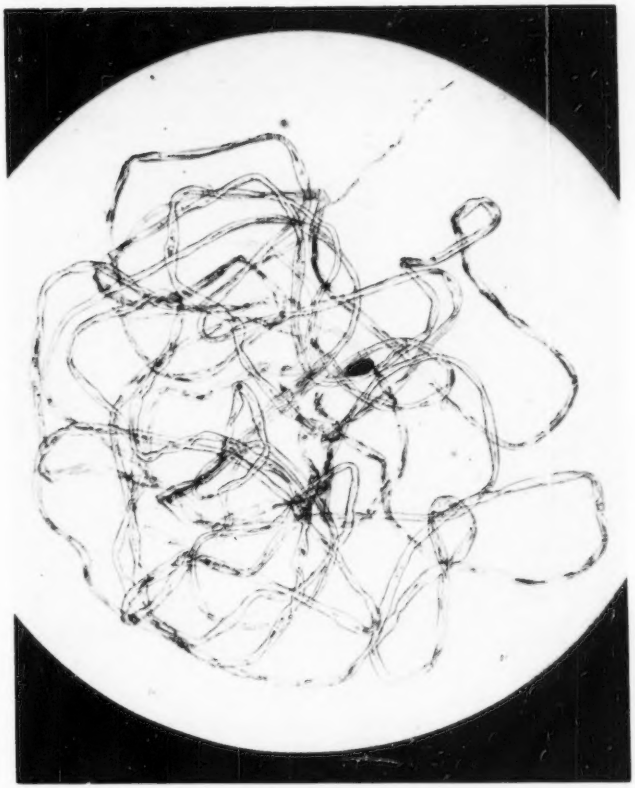

Fig. 8. *A photomicrograph of a single cotton fiber. The fiber's transparency can be observed where it crosses over itself. U.S.D.A. photomicrograph, Southern Regional Research Laboratory.*

incident light is lost within the fibers by total internal reflection, and some will pass through the entire layer of fibers to be absorbed by surfaces beneath.

The proportion of the original refracted beam that can re-emerge to add to the intensity of specular reflection will be affected by irregularities in the shape of the fiber, by irregularities in the fiber arrangements, and by materials within the fiber that absorb, diffuse, or disperse the transmitted light. Most textile fibers, the exception being glass, are not optically isotropic. In other words, their composition is not entirely homogeneous to light; thus, they commonly show two indices of refraction. Light is refracted differently in the longitudinal and transverse directions by these fibers because the long thread-like molecules which make up the fiber are preferentially oriented in the direction of the fiber axis and because the degree of packing of the fiber molecules results in the formation of crystals in some areas, which may be separated by amorphous regions. The fiber property which is characterized by two refractive indices, or by different behavior toward light in different directions, is known as optical anisotropy, or birefringence.

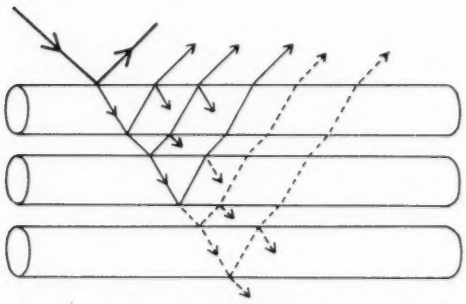

Fig. 9. *At each air-fiber boundary light is partly refracted and partly reflected.*

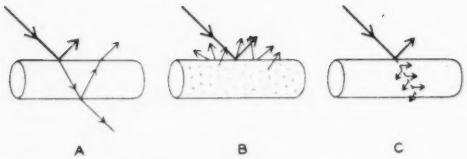

FIG. 10. *A—Bright synthetic fiber. B—Delustered fiber. C—Dull fiber relustered.*

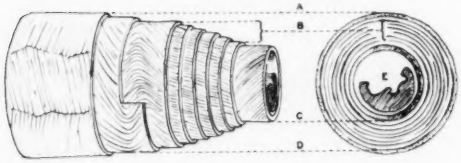

FIG. 11. *As the cotton fiber matures, the cell formed by the primary wall A is filled by successive daily deposits of cellulose in layers. D—First layer deposited within original cell. B—Central layers. C—Innermost layer. E—Lumen and residual protoplasm.*

Perhaps the influence of light which is refracted into the fiber can best be illustrated by the mechanism of delustering synthetic fibers. A normally bright synthetic fiber can be rendered dull or lusterless if during manufacture small particles of an opaque material are incorporated into the fiber. The result of this treatment is illustrated in Figure 10. In the bright fiber *A*, the reflected component plus the reinforcement from refracted and internally reflected light results in the necessary specular reflection for high luster. In *B*, the small particles on the interior of the fiber have caused the refracted light to be scattered in all directions, re-emerging from the fiber so as to completely mask the reflected component of the original beam. The reflected component is still present, however, and the fiber can be relustered if the masking effect of randomly scattered light is removed. This can be done by dyeing the fiber black, causing nearly all of the light passing into the fiber to be absorbed, so that the specular component of surface reflection is again observed without interference. This is illustrated in *C* of Figure 10.

Returning again to consideration of the cotton fiber, it can be seen that both shape irregularities and optical irregularities in composition will add to the scattering of light from within the fiber, and thus to the masking of the specular or lustrous reflection. Mercerization without tension will improve the shape without improving luster significantly, as noted above, and therefore some importance must be attached to other light-scattering influences within the fiber. For a better understanding of the nature of these influences in the cotton fiber, in Figures 11, 12, and 13 it can be seen that both the spiraling arrangement of the crystallites and the lumen or hollow center of the fiber can act to scatter light. Not only do the crystallites in cotton spiral around the fiber axis, but they change direction frequently, and the direction of the spiral in some layers opposes that in others.

At this time evidence seems to point to the crystallite orientation or spiral angle as affecting luster more significantly than the lumen. Cottons with the highest natural luster, such as Sea Islands, have the best alignment of crystallites with the fiber axis, and the dullest cottons, such as Indias, have wide-angle orientation. Crystallite orientation might also explain the influence of tension in mercerizing not accounted for by shape correction alone. Photomicrographs in Figure 14 show that as the cotton fibers are swollen and stretched, the spiral angle of the fibrils is decreased significantly. Any light-scattering effect which the fibrils have in mercerized cotton should become less random as the alignment with the fiber axis improves.

For Case *B* of Figure 3 the possible influence of crystallite orientation and shape irregularities on luster have been suggested. The third case (*C*)

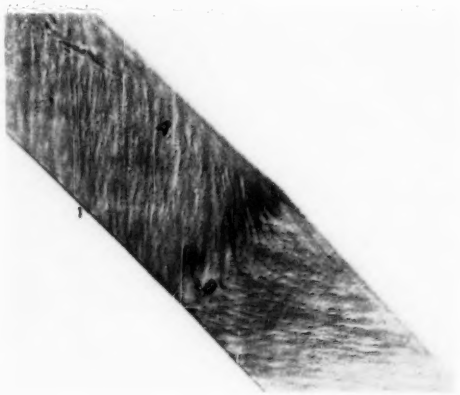

FIG. 12. *Photomicrograph of cotton fiber showing spiraling fibrils (A) and spiral reversal (B). U.S.D.A. photomicrograph, Bureau of Plant Industry, Soils and Agricultural Engineering.*

shown in Figure 3 illustrates the absorption of light passing from one medium into another, and some discussion of this will be necessary before a summary of the nature and origin of luster can be attempted.

White light or daylight is a composite of light of different wave lengths or colors, and the preferential absorption by a material of certain wave lengths gives that material the color of the light not absorbed. If all of the light were absorbed, the material would appear black, whereas if all wave lengths except red were absorbed, the material would have a red color.

In actual materials or surfaces, absorption is never perfect. In the case of the red material mentioned above, part of the incident white light will be reflected from the surfaces, and a part of the red light will be absorbed with the other wave lengths. Figure 15 shows reflectance (%) plotted against wave lengths of light (A), and here it can be seen that the effective color of the material is a combination of the reflected red light and some surface-reflected white light. Reflection of the white light

FIG. 13. *Longitudinal view of mercerized cotton fibers. Light-scattering substance can plainly be observed in the lumens of these two fibers. U.S.D.A. photomicrograph, Bureau of Animal Industry.*

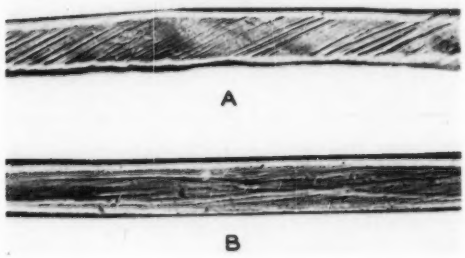

FIG. 14. A—*Unstretched fiber.* B—*Stretched fiber. U.S.D.A. photomicrographs, Bureau of Plant Industry, Soils and Agricultural Engineering. Photomicrographs of immature fibers from unopened bolls. It is assumed that the same changes take place in mature fibers when tensioned, from evidence of x-ray studies, but the effect is difficult to observe under the microscope.*

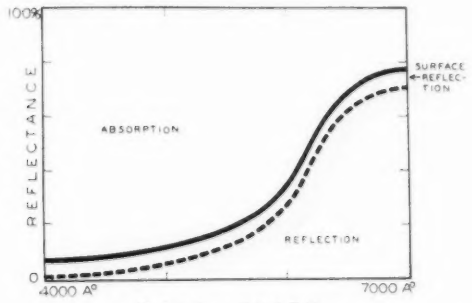

FIG. 15. *The apparent color of a red material is a combination of reflected red light and surface-reflected light of all wave lengths.*

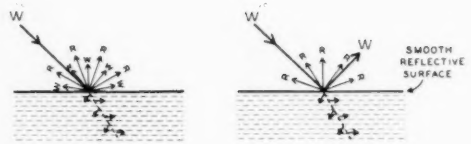

FIG. 16. *The color of the red material* A *is made brighter by concentrating the white surface reflection specularly as in* B.

FIG. 17. *Light falls on a plane pad of parallel fibers, in the fiber direction in* A, *and across the fibers in* B.

therefore dilutes the intensity of the red light, causing the shade to be somewhat paler than it might otherwise be, as illustrated in *A* of Figure 16. If the surface reflection can be concentrated in one direction and prevented from mixing with the red light at most angles, as shown in *B* of Figure 16, the full intensity of the red color will be observed. At the mirror peak the white light is at a maximum, and little red is visible, but at all other angles the red will be brighter than in the matt surface shown in *A*. The pronounced contrast between white light at the mirror peak and bright color at other angles accentuates the lustrous character of the surface. Dye shades are brighter in lustrous textiles for this reason, and at the same time luster is more apparent because of the added contrasting effect of white light against colored light.

In summary, the influence on luster of the three types of light phenomena illustrated in Figure 3 has been suggested, but no conclusions have been presented as to the relative importance of cases *A*, *B*, and *C*. Considering case *C*, first, it is obvious that the contrasting effects of color are effective only in colored goods. Furthermore, the dyes used on textiles sometimes roughen the fiber surfaces, so that although contrast tends to be improved, specular reflection may be reduced. Therefore, color may or may not significantly increase the luster effects in textiles, depending on the circumstances involved. It seems reasonable to consider color as an added effect which may enhance luster rather than a primary contributor to luster.

Which of the two factors—surface reflection or refraction and internal reflection—contributes most to textile luster? Each, of course, is affected by fiber shape and shape continuity, as well as by fiber-surface smoothness. Some clue may be obtained from the data below which were volunteered by a large rayon producer in 1936. A scale of luster was devised in which the reflectance value of 100 was given to a mirror and the value of 0 to magnesia. On this scale of reflectance, several fibers were rated as follows:

Material	Reflectance value
Mirror	100
Acetate rayon	80
Viscose rayon	70
Silk	40
Cotton	4
Magnesia	0

The fibers listed above have mean indices of refraction in the range of 1.47 to 1.57, and, as indicated earlier, the amount of incident light reflected from these fibers will approximate 4% to 5% at 45° incidence and not over 10% even at 60° incidence. Therefore, a very considerable part of the light passing into the fibers must have found its way out again to reinforce the specular component if the mirror used were 100% reflecting.*

In the synthetic fibers reinforcement of the light specularly reflected from the surface results from the mechanism illustrated in Figure 9. Refraction and reflection occur at the air-fiber boundaries, the interior being homogeneous so far as the passage of light is concerned. The optical inhomogeneity of the raw cotton fiber causes so much scattering of light passing into the fiber that reinforcement of specular surface reflection would be negligible even if the shape of the fiber were ideal. Mercerization, however, reduces internal interference with the passage of light, as evidenced by greater fiber transparency, and this change, together with fiber-shape improvement, should and probably does promote the mechanism illustrated in Figure 9. But there still remains some question as to how much of the light

* Information recently obtained reveals that the "mirror" was a highly reflective black glass cylinder. Since glass has a refractive index close to those of the fibers tested, the table shown probably does not answer the question of how much light from within the fiber reinforces specular intensity.

FIG. 18. *The mercerizing ply places the fibers parallel to the yarn axis, but the plied yarn lacks the smooth contour of continuous-filament yarns.*

entering the mercerized fiber passes completely through, how much is diffused by what remains of the lumen, and how much is scattered by the fibrillar structure. In the final section of this paper several suggestions are advanced which might provide the answer to this question.

Literature Sources: 1*, 5, 9, 11, 13, 14, 15, 16, 17, 18*, 20*, 21*, 23, 24*, 28, 29, 30, 31*, 32, 33, 34, 36, 38, 44, 45, 49, 51, 52, 53, 54*, 58*, 62*, 66, 67*, 68, 71*, 72, 73, 74*, 80, 81, 83, 87, 90, 99*, 100*, 105, 106, 114, 116, 117, 118, 119*, 121, 126, 130, 131, 135, 137, 138, 139, 140, 142, 143, 144*, 149, 150, 152, 153, 154*, 158, 159, 160*, 161*, 162*, 163, 166, 167, 168, 176, 178, 180, 184, 187, 188, 191, 192, 196, 199, 204, 205, 206, 207, 208, 210, 211, 214*, 216, 217, 218, 219.

Fabric Design and Construction

A few simple rules for constructing fabrics of good luster can be developed from the basic principle that a pad of parallel fibers produces maximum values in reflectance. In a pad of parallel fibers, brightest luster (maximum specular reflection) occurs when the plane of incident and reflected light parallels the direction of the fibers in the pad, and luster is least discernible when the plane of incident and reflected light is perpendicular to the fibers' axes (Figure 17). This preferential reflection causes the changes in luster values from different angles of viewing a fabric and thus effects the contrasts that contribute so much to luster.

* It is suggested that literature references marked with asterisks be consulted first in making a detailed study of the subject matter reviewed in a section. There is no implication that references so marked are more valuable than other sources; the distinction is merely that they have been especially helpful in the preparation of this review.

In general, constructions in which the fiber arrangement most nearly approaches a pad of parallel fibers exhibit the greatest luster. Departures from this ideal, such as twist, yarn crimps, fiber kinks, and loose fiber ends which cause fuzziness, tend to reduce luster. The appeal of luster is not directly related to the intensity of specular reflection, however, and in many cases attractive luster in fabrics is dependent on a pleasing contrast of moderately reflective regions against a duller background. The choice of colors can further accentuate lustrous effects, both by contrast in colors and by the use of colors to which the eye is especially sensitive. Therefore, fabric design for luster must be based on a recognition of both the importance of specular reflection and the significance of contrast.

Considering first only specular reflection, it is immediately apparent that continuous-filament yarns have a twofold advantage over all spun yarns; freedom from fuzzy, light-scattering fiber ends, and a lower required twist. Nevertheless, manufacturing processes for the spun yarns have partially overcome the superiority of continuous-filament yarns in these respects. The practice of doubling spun singles in an opposing direction returns the twisted fibers to a position parallel with the fiber axis, and gassing or burning off the fuzz fibers improves surface smoothness. Figure 18 compares a two-ply spun yarn with a continuous-filament yarn. While the fiber alignment in the spun yarn is even better than that in the lightly-twisted filament yarn, the doubling twist unfortunately has introduced a discontinuity that results in a series of bright spots rather than the smooth uniformity of highlight in the filament yarn.

Twist in yarns reduces the effective length of fibers lying on the upper surface of a yarn in a fabric, and as this effective length decreases, luster also decreases. Twist also rotates the direction of maximum specular reflectance from that of the yarn axis in the case of no fiber twist to a new point which corresponds to the inclination of the fibers in the yarn. Both the effect of twist on intensity of reflectance and its directional effect on reflectance can be observed nicely by measuring the specular reflectance from fabrics rotated in their own plane from 0° to 360°. If, for example, warp sateens are chosen, in which the warp twist differs from sample to sample and the filling twist is kept constant, the observations of specular intensity will be as shown in Figure 19. Note the decrease in warpwise reflectance and its shifting as twist increases.

The curves in Figure 19 indicate contrasts in intensity of specular reflection at different angles of viewing. Contrast is greater, however, between the angle of specular reflectance and some other angle, such as perpendicular viewing for 45° illumination. Constructions which provide parallel fibers, and parallel surface yarns as in sateen floats, concentrate the greatest possible amount of light in specular reflection and thus produce, in the float direction alone, the maximum contrasts which result in highest luster effect. The greater contrasts in the float direction can easily be seen in damasks, in which yarn floats form patterns on the fabric surface. At specular angles, the float-depicted patterns stand out brightly from a duller background of filling yarns. However, at other angles the filling yarns appear brighter than the warp patterns.

In referring to textile luster, it is perhaps best to consider angles of specular reflectance rather than one particular or control angle. In almost all cases the surface fibers or yarns are sufficiently curved so that within a range of angles the specular intensities may be nearly equal. For long surface floats this range becomes narrow and contrast effects are therefore highest. For shorter floats contrast diminishes but sometimes other special effects appear, one of which is double-peaked reflectance. Fabrics which show two angles of maximum reflectance are rather rare, but the phenomenon is interesting and therefore is shown diagrammatically in Figure 20.

Fabrics with relatively flat surfaces lend themselves better to luster development than those with a rough or nobby texture. Here again, the reason can be traced to a better approach to the ideal condition of a pad of parallel fibers. Oxford and basket-weave shirtings, in which two warp yarns may be woven together over one filling yarn or four warp yarns over two fillings, or some similar arrangement, are noted for good luster even though singles yarns are used. Certain other constructions utilize heavy soft-twisted yarns in one direction interwoven with finer yarns in the other, so that the heavy yarns produce a surface suitable for pressing or calendering and especially for embossing or Schreinering (see below). A warp rep is an example of such a fabric.

Uniformity is one of the keys to good luster in textiles—its importance traces all the way from uniformity in fiber cross section to yarn evenness and to uniformity of construction in the fabric. Luster arises from the uniform reflection of light, and all

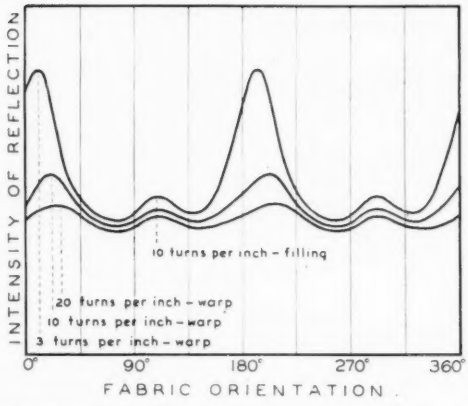

FIG. 19. *The effect of twist on the orientation and intensity of luster peaks.*

irregularities and uneven places in yarns and fabrics break up in some manner the desired uniform reflection. Photometric measurements show that even irregularities in the singles twist and the doubling twist of yarns reduce luster.

Kinkiness or crimp in fibers might be considered a nonuniformity, and this irregularity, whether natural or artificially introduced, reduces luster markedly. For example, a yarn of crimped viscose staple has a decidedly dull and delustered appearance normally, but when the yarn is wet and rewound under tension to remove the crimp, the yarn takes on a lustrous appearance. Kinks in cotton fibers which prevent their assuming a smooth, parallel arrangement diminish the luster of cotton products. It seems likely that at least one of the functions of tension during the mercerization of cotton is removal or reduction of fiber kinkiness.

Finally, color must be considered in the design of lustrous fabrics. In the preceding section it was seen that color increases the contrast between specularly reflected white light and diffusely reflected light. The greatest contrast exists in a black fabric where the white highlight contrasts with a black background. One technologist has pointed out that this is why black horses look more shiny or lustrous than white horses. Similarly, fabrics with alternate black and white stripes accentuate luster by the contrast of reflection and absorption from adjacent stripes.

In some cases the effect of luster is achieved in fabrics largely through the use of contrasting color.

Certain constructions which use red warp yarns and green filling yarns, for example, seem to change color depending on the angle of viewing and illumination. These "shot cloths," sometimes called iridescent or changeable cloths, have an effect very similar to that of luster, although in this case the contrast is between the characteristic wave lengths of the reflected light rather than between intense and low reflection. Shot cloths have for years been produced principally with silk and the rayons for use in women's dress fabrics and linings. Recently, however, iridescent cottons have been popularly received as fabrics for women's dresses.

Fabric design and construction have an important relationship to textile luster as well as to many other textile qualities. Certain fiber characteristics are prerequisites for good luster, but even with the most lustrous fibers the design and construction of the fabric can greatly modify the final textile luster. The constructional and design properties which affect luster most directly range from characteristics of the fiber to those of the final fabric. Fiber cross section should be elliptical to round, with continuity of shape an important factor. Fiber diameter is not a critical influence within the normal range of textile fibers. Fiber length has no effect except through the greater number of ends per unit yarn length and the higher twist requirements for short fibers. Fiber crimp or kinkiness reduces luster, as do all nonuniformities in the manufacture of both yarn and fabric.

Generally, fine yarns permit smoother fabric surfaces, although some soft-twisted heavy yarns can be compressed to a desirable flat surface. Yarn twist should be at a minimum for highest luster, but patterns and designs can be accentuated by the luster contrasts of yarns having different amounts of twist. Singles yarns can be doubled or plied so that fibers closely parallel the yarn axis. In the fabric, smooth surface constructions are best for luster, and those with sateen floats produce the highest specular contrasts.

Literature Sources: 1*, 2*, 3*, 4*, 35, 62*, 69, 114*, 130*, 135, 154*, 161*, 162*, 164, 169, 170, 182, 198, 201.

Luster Finishes

The use of finishing processes which improve the luster of cotton yarns and fabrics has been widespread for the last half-century. The principal luster process in use today is mercerization, but other chemical treatments, together with several methods of finishing cottons mechanically, add luster with various degrees of effectiveness and permanence. The total volume of cotton yarns and fabrics finished for higher luster can reasonably be taken as another indication of the demand for this quality in cotton.

The degree to which available finishes are providing consumer satisfaction, however, is a subject which deserves further discussion. Certainly, mercerization gives an extremely valuable finish, improving both luster and other properties of cottons. Other finishes are useful when a lower cost is necessary, and sometimes to further enhance the effects of mercerization. Therefore, no disparagement of present finishing processes is intended in this paper, although it must be stressed that higher degrees of luster than are now obtainable are to be desired and that luster finishes should combine effectiveness, durability, economy, and a wider applicability in a manner not now possible with the finishes reviewed below.

The chemical and mechanical finishing processes for improving the luster of cottons which are outlined briefly are believed to be the chief methods available for this purpose. No attempt is made to present the special adaptations or refinements used by some manufacturers which contribute to the "know how" so important to most finishing operations. The emphasis will be more on the manner in which each finishing treatment brings about the higher luster in cotton yarn and fabric.

Mercerizing. Mercerizing, after more than 50 years of use, is still the best process for improving the luster of cotton. The success of this treatment results from the durable type of luster obtained and from the fact that other properties of cottons are improved rather than diminished by the treatment. Besides increasing luster, mercerization makes cotton stronger, more absorbent, and easier to dye and finish.

FIG. 20. *A concentration of specular reflection may occur in regions where the slope of the yarn is changing slowly, thus causing double-peaked luster.*

The mercerization process today is practically the same as it was when originally developed. Machinery for mercerizing has been improved and refined to some extent and a few new types of machines have been developed, but the essential features of the process still consist of treating the yarn or fabric while it is under tension with caustic soda, with occasionally some additional stretching, followed by washing for removal of the caustic soda.

Yarns are mercerized in the form of either skeins or warps. The continuous mercerization of yarns in warp form is the faster and cheaper of the two methods and the more widely used where sufficient quantities of yarn are to be processed.

In warp mercerizing it is customary to use warps weighing about 180 lbs. and having 378 ends. Thus, the size of the yarn determines the length on each warp. A number of these warps, sometimes as many as 80, are mounted behind a compartmented box machine. The spread-out yarns pass into the box machine almost as a fabric, making several dips in each compartment and usually passing between nip rolls in going from one compartment to the next. In a typical operation of this sort the first two compartments of the box machine will contain hot water, at about 200° F, which serves for initial boil-off and swelling. The next two or three compartments contain 22% caustic soda solution, flowing counter-current to the yarns. After going through the caustic soda compartments, the yarn passes into two or three wash tanks, a tank containing 3% sulfuric acid for neutralization, and then through additional tanks which wash the yarn further. The final tank may contain a softener, a whitening or bluing agent, or some other special finish. On leaving the box machine the yarn is continuously dried either in a festoon or loop drier or over steam-heated cans. The caustic soda washed out of the yarn is recovered by evaporation of the wash liquor, recovery usually being 90% to 95%. Tension on the yarn is kept constant throughout the machine in most cases, although finishers vary their techniques somewhat on this point, as well as on the concentration of caustic soda, the temperature of the caustic soda solution, the time of immersion, and other details.

Skein mercerization is usually employed for smaller lots of yarn or when some special handling is necessary. In a typical skein-mercerizing operation the skeins are placed around heavy metallic spools which are located on a movable frame. The spools are drawn apart until the skeins are tightened, whereupon the entire frame is lowered into a vat of approximately 22% caustic soda. After a short period of immersion, usually 2 to 3 minutes, during which time the spools revolve so that the yarns will be thoroughly impregnated, the rack is raised, and the skeins are washed under tension while the spools revolve first one way and then the other. Some additional stretching may be done at this point. The operation is concluded with more washing, possibly with an acid sour, a further rinsing, and then drying.

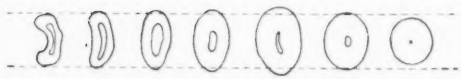

FIG. 21. *Shape changes in the cotton fiber during mercerization.*

Fabric mercerizing is much the same as yarn mercerizing except that tension must be maintained in two directions instead of one. To accomplish this, after the usual impregnation with caustic, the fabric feeds directly onto a tenter frame which keeps the width pulled out against the shrinking action of the caustic. Sometimes, additional stretch is introduced on the tenter frame, but in any case the tension is maintained until the fabric is washed nearly free of caustic.

An additional process, known as gassing in the case of yarns and singeing in the case of fabrics, is often employed to increase luster and smoothness further. The object of the gassing or singeing operation is to remove the fuzzy fiber ends which in spun yarns tend to screen or to diffuse luster. The fuzz fibers are burned off the yarn by causing the yarn in open warp form to be drawn quickly over or through a uniform gas flame. In singeing fabrics, the cloth may pass through a flame similar to that used for yarn gassing, or it may pass between red-hot plates or rollers. The speed is rapid enough in both gassing and singeing so that only the fuzz fibers are burned, the yarn or fabric being unaffected.

During mercerization the cotton fiber, if unrestrained, shrinks in length from 14% to 17%, while at the same time the cross section of unconfined fibers increases by about 75%. Swelling also takes place into the lumen, so that the swollen cotton may have three to four times its original volume (Figure 21). As swelling proceeds, the convolutions in the fiber are removed and the fiber assumes a more rod-like form. Luster is not increased, however, unless mercerization is carried out under tension, even

though shape and shape continuity are much improved in swollen and unrestrained fibers (Figure 22). Several explanations for the function of tension in mercerizing have been offered, but none seems to be entirely satisfactory.

Among the several possible functions of tension in mercerizing are: (*a*) tension carries shape improvement beyond the improvement brought about by swelling alone, the shape of the fiber approaching more closely the ideal rod-like shape; (*b*) tension or restraint of the fiber against its own shrinking action serves to remove fiber kinks, thus permitting a more parallel arrangement of the fibers in the yarn; (*c*) tension helps remove "wrinkles" on the fiber surface

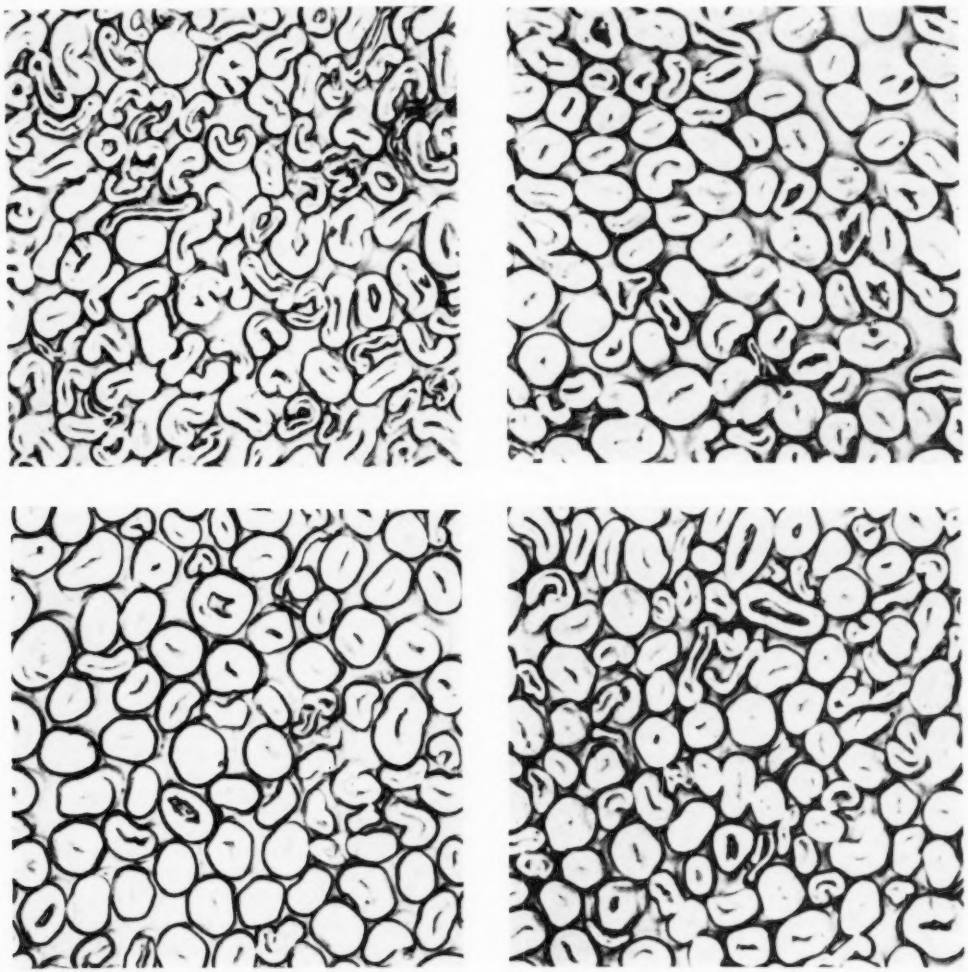

FIG. 22. A (top, left)—*Cross section of Rowden 8/1 carded yarn, raw.* B (top, right)—*Cross section of Rowden 8/1 carded yarn, mercerized unrestrained.* C (bottom, left)—*Cross section of Rowden 8/1 carded yarn, mercerized at normal length.* D (bottom, right)—*Cross section of Rowden 8/1 carded yarn, mercerized with 6% stretch. B shows hardly any luster improvement over* A, *but in* C *luster is greatly improved, and is still higher in* D. *Other factors than cross-sectional shape improvement evidently influence luster significantly.*

as shape improves in the course of swelling; (*d*) the change in fibrillar structure, with improved axial orientation, reduces the scattering of light refracted into and through the fiber; (*e*) the greater transparency of the mercerized cellulose permits more reinforcement of specular reflection from light refracted into the fiber.

The further development of mercerizing, and of processes similar to mercerization, depends on how much is learned about the relative importance of changes in fiber structure and in fiber, yarn, and fabric form which are responsible for luster. At this time technologists either do not agree on the reasons for luster development by mercerization or they admit that further study must be undertaken before definite conclusions can be drawn. With the research tools available today and with our more advanced knowledge of fiber structure and properties there appears to be an unusual opportunity for resolving the questions about mercerizing that still remain unanswered and thereby greatly advancing our knowledge of luster in cotton.

Cuprammonium Finish. One of the oldest and best-known swelling agents for cellulose is Schweizer's reagent, $Cu(NH_3)_4(OH)_2$. There are innumerable variations of the cuprammonium solution which can be prepared from aqua ammonia and copper hydroxide, copper carbonate, copper sulfate or chloride with caustic, or metallic copper. Warm cuprammonium solution has little or no swelling action on cellulose, but when the solution is cooled, preferably to the neighborhood of 20° to 30° F, the cellulose swells rapidly and will go completely into solution unless the reaction is stopped.

The cuprammonium finishing of yarns, and more particularly of fabrics, is even older than the mercerizing process. A multitude of patents have been taken out on cuprammonium finishes, a large number of which have now expired. Most of these patents cover slight variations of the general principle which, in brief, involves passing the fabric through a bath of cold cuprammonium solution, scraping or squeezing to remove excess solution, heating to decompose the copper-ammonia complex, removing the copper salts with dilute acid, washing, and drying. Sometimes the fabric is completely dried before the copper salts are removed, while in other cases the copper compound may be left on the surface of the fabric or may be replaced by chrome or iron salts or converted to the sulfide.

The principle of the cuprammonium process is the same in all cases despite the many variations that have been used from time to time. The cuprammonium solution dissolves the fuzz fibers of the fabric and swells and partially gelatinizes the surface yarns. When the reaction is stopped by heat or acid, cellulose in regenerated form is deposited on the fabric surface, and fibers that have been partially gelatinized are fused together. Calendering during the operation further flattens the surface so that the resultant fabric has a smooth, slick surface free from the fuzz fibers which normally interfere with reflection. The cuprammonium process imparts a higher luster to fabrics than do other chemical finishing processes, but leaves the fabric with a changed hand because of the stiffening effect which results from a cementing together of the fibers.

The cuprammonium finish is much less widely used than the mercerizing process. As commonly applied it is a surface finish, although it has rather good durability. It does not increase strength and absorbency or improve dyeing properties, as does the mercerizing process, which affects each fiber. Nevertheless, the cuprammonium process is suitable for many special applications, and offers interesting possibilities for further development.

Additional Chemical Finishes for Luster. A number of other swelling agents have been used for increasing the luster of cotton, some commercially and some only experimentally. Sodium zincate-urea has been used in much the same manner as the cuprammonium solution for producing a lustrous fabric by surface regeneration and redeposition of cellulose. The use of this agent, however, offers no particular advantage over cuprammonium.

One chemical manufacturer has reported that strength increases are almost doubled and luster is substantially improved by pretreatment of cotton with acrylonitrile before mercerization. The cotton yarn or fabric is impregnated with acrylonitrile and the excess is hydro-extracted prior to the regular mercerization. Apparently, the process has never been used commercially because of the toxicity of the acrylonitrile.

A process for imparting luster, added body, and a rather parchment-like feel to cotton fabrics involves passage of the fabric through concentrated sulfuric acid. This strong acid rapidly removes the fuzz fibers on the surface of the fabric or yarn and at the same time starts a swelling of the cellulose that would, if unchecked, soon cause decomposition.

FIG. 23. *Flattening of the fabric during calendering. B is intended to illustrate the surface flattening and compacting that results from calendering a fabric A.*

The fabric is quickly passed into washing and neutralizing baths, however, to stop the reaction before it has gone too far. Obviously, this type of finishing requires extremely careful control, and for that reason, and because of the changed hand of the cloth, it has not found wide usage in this country.

Mechanical Finishes. In addition to the chemical finishes, there are a number of mechanical finishing processes which improve the luster of cotton fabrics. These finishes are nondurable unless they are used in combination with resins which can be fused or set to a definite surface form. The wide use of mechanical finishes for luster improvement stems from their low cost and the ease with which they can be applied and from the fact that even a temporary luster adds immensely to the sales appeal of textile products.

One of the oldest and most widely used mechanical finishes is the Schreinering process. Cloth is passed through a pair of calender rolls on the surface of which a great number of very fine lines are engraved. The steel rolls, heated to a temperature of nearly 600° F, exert a heavy pressure on the fabric and thus impress upon its surface the pattern of fine parallel lines. The flattening of the fabric and the formation of parallel ridges increase specular reflection in the direction of the lines, which results in a pleasing lustrous effect.

Several other types of calendering which do not employ the engraved rolls of the Schreinering process are used to produce various effects of luster and hand in cotton fabrics. Most of the calender finishes have the general effect of making the cloth more compact and less porous and of flattening and smoothing the surface (Figure 23). The cloth is usually dampened and run through the calender in a preliminary operation, after which it is conditioned for an hour or so to allow for some fiber swelling and consequent fabric compacting.

Three types of calendering are in general use. In swissing, the cloth passes between two or more rolls of the calender which revolve at the same speed as the cloth. The rolls may be hot or cold, and speed and pressure can be varied to give heavy or light finishes. The chasing type of calendering is similar to swissing except that the fabric passes between the same rolls two or more times, so that a pressure of fabric against fabric results. The luster developed by the chasing calender has a lower specular value than that from swissing, but a moiré or watermarked type of finish forms contrasts and shifts in luster that make the chased finish of interest. The highest gloss finish by calendering is the "glazed" type produced by the friction calender. In this treatment the rolls turn faster than the fabric, polishing the surface and closing the interstices between yarns.

In embossing, fine parallel lines are impressed on the surface of the fabric in a manner similar to that of the Schreinering process. The lines may be cut away in part, however, to form patterns or they may be engraved in different directions in different parts of the design. If the embossing is done on a fabric that has been back-filled or otherwise impregnated with a thermo-setting resin, the design or pattern is impressed on both the resin and fabric. After the resin has been cured and the fabric washed, rinsed, and dried, a pleasing and durable finish is obtained in which the design effect is the result of preferential light reflections from the etched lines on the cloth's surface.

Durable glazed chintzes and similar fabrics are produced in a manner similar to resin embossing except that the surface of the embossing rolls is smooth. Variations in the several steps of the resin-glazing process give different degrees of luster and a range of values in hand of the finished fabric.

Mercerizing is the only durable luster finish that does not alter the hand of fabrics or diminish the usefulness of their physical properties. A higher luster can be obtained with the cuprammonium process, but only at the sacrifice of hand, tear strength, and with a change in texture. Luster can be improved by Schreinering, chasing, and beetling without undesirable changes in hand, but the finishes are nondurable and will be removed by water-spotting or washing. The resin-glazing and resin-embossing finishes produce a high luster, but hand is affected, tear strength usually reduced, and absorbency generally decreased.

Literature Sources: 10*, 11, 12, 21*, 27, 39*, 43, 55*, 57, 63, 68, 69, 70, 75, 76, 79, 82, 85*, 86, 122, 130, 136, 148, 179*, 200.

Luster Measurement in Textiles

The dependence of luster on not only physical phenomena but on psychological and physiological factors as well suggests that complete evaluation or measurement of the property might present almost insurmountable difficulties. Luster is a sensory property commonly evaluated by the eyes, and although the eyes are remarkably efficient in measuring relative luster within certain ranges, the evaluation generally differs somewhat with the observer. Moreover, visual rating of luster is suitable only for comparisons and provides no luster index or permanent record. The technologist who studies luster needs a yardstick with which he can compare with confidence the luster of the various textile samples with which he is concerned. Instruments and methods are available which permit him to measure at least some of the physical phenomena of luster, but correct interpretation of the psychological factors is much less certain, and almost nothing can be done instrumentally to measure physiological factors such as binocular luster or "Dove" effects (see below).

It must be conceded, therefore, that much study and further development of methods of measuring textile luster are necessary. Anyone who pursues this line of study should be aware of the following considerations which bear directly on the problem:

1. Intensity of specular reflection. Textiles reflect specularly not more than 4% to 8% of the incident light from the fiber surfaces, but that amount may have considerable reinforcement from light refracted into the fibers. The amount of light concentrated in specular reflection is certainly one of the important factors in textile luster value; it is known as "objective" luster.

2. Contrast reflection. In textiles, where the surface is generally flexible and assumes varied contours, the conditions of illumination and reflection change from area to area. The resultant contrasts between specular and diffuse reflectance might fairly be said to be the most important contributing factor to the sensory impression of textile luster. The contrast between specular reflectance and diffuse reflectance is known as "subjective" luster.

3. Surface texture. Even though two textile fabrics may show the same specular reflectance and also the same contrast or subjective luster, when evaluated visually this luster quality may be quite different simply because of differences in surface texture. Some provision should be made for recognition of differences in texture, since texture is probably more significant in textiles than for most other types of surfaces.

4. Color. Where color is involved, both objective and subjective luster are affected. The sensitivity of the eyes to certain wave lengths of light differs from that of the photocells used in photometric instruments. Furthermore, contrast luster is enhanced by color, the degree depending on the color, while specular intensity may remain constant. If colored light illuminates the specimen, even the objective luster will be changed.

5. Binocular effects. The transparency of textile fibers and the depth of relatively fine refracting and reflecting surfaces which compose the average textile surface cause reflected light to reach each eye from a slightly different angle or distance. Furthermore, each eye observes a slightly different illumination in the tiny ridges of the fabric surface. This stereoscopic effect and the sense of indeterminate depth materially influence visual judgment of luster, but although the phenomena were recognized by Dove as long ago as 1857 no instrument has been developed which can satisfactorily measure these binocular effects.

6. Dynamic effects. Since contrast, or subjective luster, is one of the most important considerations in textile luster, the ease with which a fabric lends itself to folds and to different shape configurations necessarily influences the sensory impressions of luster. The sharpness of folds, the flexibility and consequent rapidity of shape changes, and the freedom from wrinkles that interrupt specular surfaces all affect luster as evaluated visually.

The number and variety of photometers and instruments that have been developed are quite extensive despite the difficulties in fully interpreting luster. There is little of value to be gained from a detailed description of many of these instruments, especially those which were designed primarily to measure the gloss or luster of surfaces which are quite different in character from textiles. The general principles of a number of methods can be described, however, and some details can be given on accepted methods applicable to textiles.

Harrison, in his monograph "Definition and Measurement of Gloss," outlines six general types of luster measurement. Only four of these methods seem applicable to textiles, and since two of the four are the same in principle, the methods outlined here will be: (1) objective luster measurements; (2)

subjective luster measurements; and (3) goniophotometric measurements.

1. "Objective" luster measurements involve a determination of the amount of light that a surface can reflect specularly. In instruments which measure objective luster, light falls on the test sample from some chosen angle, usually between 45° and 80° to the normal, and the intensity of the reflected light is measured from the corresponding specular angle. The proportion of incident light reflected specularly by the test specimen is compared with that reflected from some glossy surface chosen as a standard. No measurement is made of light reflected at any but the specular angle.

The objective luster method provides a rating of one of the parameters of textile luster—the ability of a surface to reflect light specularly. None of the important effects of surface texture and depth are recorded by this method, however, and the primary considerations of contrast and color contrast are not taken into account. Objective luster measurements are probably most useful for comparisons of the effectiveness of various luster finishes on similar materials and for adaptation to the continuous measurement of luster during the manufacturing or finishing of textiles.

2. "Subjective" luster methods attempt to measure the contrasts between specular and diffuse reflection that perhaps contribute most to visual impressions of luster in textiles. In these methods reflected light is measured in two directions, one of which is always that of specular reflection. The other direction of measurement may be any angle decided upon, although most frequently the normal to the test surface is used for the diffuse reflectance measurement. The ratio of specular intensity to diffuse intensity is used as an index of luster.

Like the objective measurements, values of subjective luster include none of the effects of surface texture, color, or binocularism. Subjective luster measurements generally give a better rank correlation with visual estimates of the luster of different types of surfaces than do the objective methods. In both the objective and subjective methods, the angle chosen for specular measurements may give reflection and intensities appreciably lower than those at some other angle where reflection may be especially influenced by surface texture. The contrast, or subjective method, tells nothing about the change from specular intensity to diffuse intensity. This change may be quite abrupt in some fabrics, while in others a more gradual change causes luster to be less noticeable.

3. Goniophotometric methods are the fundamental physical methods for studying the lustrous or light-reflecting properties of surfaces. The intensity of reflected light is observed at all angles in the plane containing the angle of incidence. A curve or a family of curves is obtained which rather completely describes the light-reflecting properties of the material. Goniophotometric methods have limited value for routine measurements because of the time and effort involved in obtaining the numerous readings, and because full interpretation of the resulting curves demands mathematical analysis, but they are a valuable research tool where detailed information on the reflecting characteristics of a surface is desired.

Each of the three general methods listed above will give some interpretation of the effect of color if color filters are used. There is no assurance, however, that the instruments thus modified will be affected by color in the same manner as are the eyes. Moreover, none of the methods adequately interpret the texture and binocular effects of which the eyes are so conscious. Therefore, it seems likely that visual observations will continue to be necessary for the final appraisal of textile luster.

The luster or reflectivity of textiles may be measured in fibers, yarns, or fabrics. The preparation of the sample for photometric measurements depends somewhat on the requirements of the instrument being used, although certain principles are generally applicable. Measurements on fibers are carried out on plane pads of fibers which have been parallelized by combing. With relatively short-staple fibers such as cotton a sample of limited area can be prepared, usually one less than an inch in length. The fiber pad should have appreciable depth so that no effect from the support or mounting is recorded and so that light refracted and reflected from within the pad can be registered.

Yarns are usually wound on cards to obtain flat pads of parallel threads, enough layers being used so that the incident light "sees" only the yarns and not the card beneath. Specular and diffuse reflectance measurements are taken in the direction of the yarns, unless for some special reason the diffuse reflection across the yarns is to be studied. A few instruments have been designed to study yarns or fabric mounted in cylindrical form in much the same condition as yarn on a spool or bobbin. It is gen-

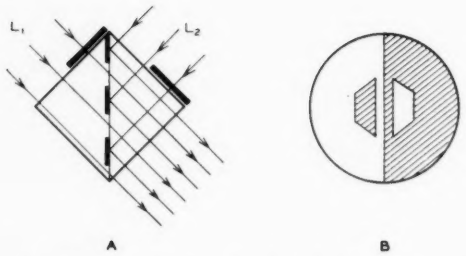

FIG. 24. *The Lummer-Brodhun Cube* (A) *provides a means of contrasting* (B) *the intensities of two sources of light.* L_1 *and* L_2 *are the two light sources.*

erally most convenient, however, to measure fibers, yarns, and fabrics in plane or flat form.

Apparently, few of the instruments described in the literature have been widely accepted for textile use, at least in their original forms, because many laboratories still employ "home-made" versions for their measurements. The use of these instruments increases still further the number of methods that have been used at one time or another, and therefore this paper will describe only a few instruments which typify different methods or which are commercially available today. It should not be inferred that those instruments discussed herein offer any advantages over others which are not described.

Until the development of the photoelectric cell, photometers were dependent on visual comparisons of light intensity. Comparison was made between light reflected at different angles from the same sample or between light reflected from the test sample and some standard reflecting surface. The Lummer-Brodhun Cube, illustrated in Figure 24, is used in many visual photometers since it permits the intensity of light from two sources to be contrasted and brought into balance. The cube is composed of two prisms which have been cemented together so closely that the cleavage is not optically effective except where the glass has been ground. Therefore, light from L_1 passes straight through the clear portions while light from L_2 is reflected through 90°. The appearance of the resultant comparison surface depends on how the prisms are ground and what shields are used, but the effect illustrated in *B* of Figure 24 may be considered typical.

Jones' contrast gloss-meter, shown diagrammatically in Figure 25, illustrates one of many methods for measuring contrast gloss visually with the aid of a Lummer-Brodhun Cube. Light from the source *A*

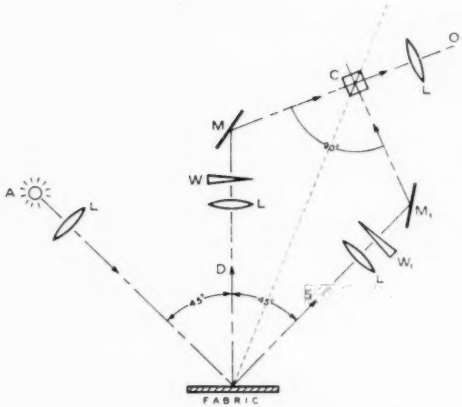

FIG. 25. *Principle of Jones' contrast gloss-meter.* W *and* W_1*—Optical wedges.* M *and* M_1*—Mirrors.* L *—Lens.* C*—Lummer-Brodhun Cube.* A*—Light source.* D*—Diffusely reflected light.* S*—Specularly reflected light.* O*—Observer.*

impinges on the sample at an angle of 45°, and the specularly reflected beam follows the path shown at *S* while the diffusely reflected light is shown at *D*. These two beams as seen by the observer at *O* can be adjusted to equal brightness by the use of neutral glass wedges shown at *W* and W_1. The inverse ratio of the transmissions of the wedges gives the relative brightness of the two reflected beams.

Figure 26 illustrates the Goerz Luster-Meter which operates on the same principle. Reflecting prisms P_1 and P_2 are used instead of mirrors. The specular angle chosen need not be 45°, and the angle

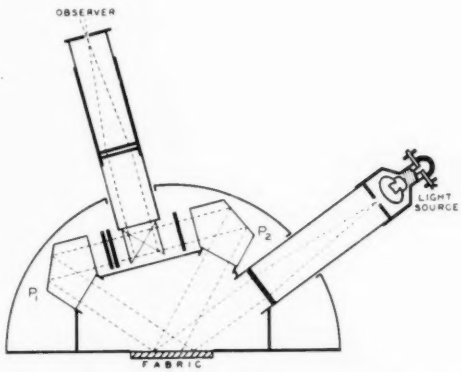

FIG. 26. *The Goerz Luster-Meter.* P_1 *and* P_2 *are the reflecting prisms.*

used for measuring diffuse reflection is also arbitrary. The lack of accepted standards for illuminating and viewing in luster determinations means of course that luster values or luster numbers have no wide usefulness and therefore are not generally accepted.

The visual photometers have been used for objective as well as subjective luster measurements. In Pelton's Photometer, shown in Figure 27, the test sample T can be rotated several ways and its specular or diffuse reflectance balanced in intensity with light from the standard surface which can be varied by moving the light L_1 towards or away from S.

The majority of photometers and luster meters in use today utilize photoelectric cells whose action is due to the emission of electrons when the cell is energized by light. The resultant electric current in the case of photomissive cells or potential in the case of photovoltaic cells can be measured by suitable electrical instruments. Trained observers are not needed with photoelectric instruments, the reflection values being recorded by precise electric meters. Photoelectric cells are not always influenced by light in the same manner as the eye, however, and the cells may be especially different from the eye in sensitivity to certain colors. The action of the cells changes somewhat when they are "warmed up," and where two or more cells are used in one instrument it is important to have both their time-function characteristics and their wave-length-sensitivity characteristics balanced.

A simple photoelectric photometer is shown diagrammatically in Figure 28. Two cells are used to eliminate error due to fluctuations in the source light by causing each reading to be a ratio of the intensities of the light striking the two cells. In an instrument of this type, objective measurements may be made by comparing the specular intensity from the sample with that from a standard glossy surface, the intensity of illumination being held constant. The subjective or contrast luster may be observed if arrangements are made to record the intensity of light reflected normally from the surface of the test sample. Since the specular readings may be considered to be made up of both specular and diffuse light, the ratio is best expressed as follows:

$$\text{Luster index} = \frac{I_s - I_d}{I_d},$$

where I_s is the specular intensity reading and I_d is the diffuse intensity reading.

An instrument such as that shown in Figure 28 may also be used for goniophotometric measurements. In this case provision is made for either the light source with its photoelectric cell or the receiving cell to assume different angles of incidence or reflection with respect to the fabric. If, for example, the reflectance cell is kept stationary at 45° and the light source and its cell are inclined at different angles to the normal, curves for reflected intensities such as those shown in Figure 29 will result. These curves provide considerable information about the fibers, yarns, or fabric being studied. A whole family of curves can be obtained if the sample is rotated in its own plane.

The Hunter Multipurpose Reflectometer (Figure 30) has been found by several laboratories to be a useful and versatile device for studies on textile luster. Light can take three different paths in the instrument. Specular intensity at 45° can be compared with that of a standard, thus measuring objective luster. Subjective or contrast luster can be obtained by measurements of 45° reflectance and reflectance perpendicular to the fabric. Light transmission can be recorded by directing the beam of

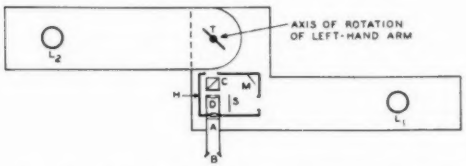

FIG. 27. *Pelton's Photometer.* H—*Photometer head.* C—*Lummer-Brodhun Cube.* D—*Lens.* A—*Achromatic eye-lens.* B—*Viewing position.* S—*Comparison surface.* M—*Mirror.* T—*Test surface.* L_1 *and* L_2—*Illuminating lamps.*

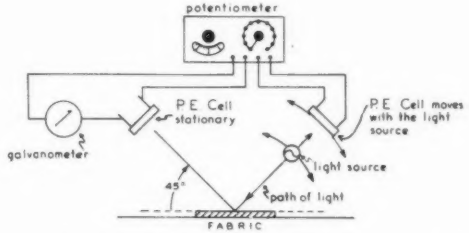

FIG. 28. *Method of Ransom and Edelstein which can be used for contrast luster or goniophotometric measurements.*

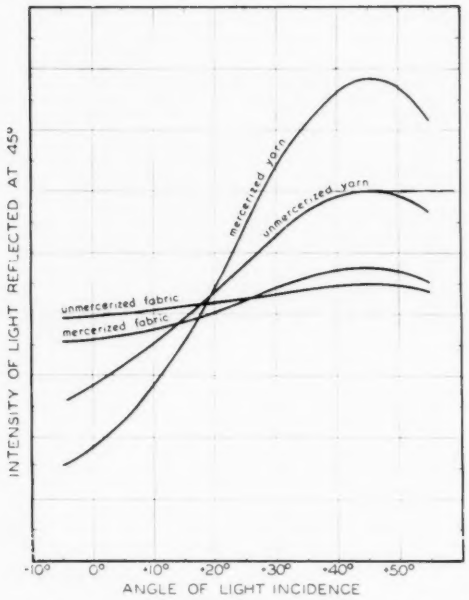

FIG. 29. *Commercial yarn mercerization is nearly twice as efficient as fabric mercerization. This fact, together with the absence of crossing yarns and crimp, results in greater reflectance contrasts in the yarn measurements.*

light straight through the fabric. There are also special attachments which permit measurements of specular intensity at 60°.

Literature Sources: 6, 7, 8, 19, 20, 22, 25, 26, 37, 40, 41, 42, 46*, 47, 48, 50, 56, 59, 60, 61, 64, 65*, 71*, 72, 73, 74*, 77*, 78, 84, 88*, 89, 90*, 91, 92, 93, 94, 95, 96*, 97, 98, 101, 102, 103, 104, 107, 108, 109, 110, 111, 112*, 113, 115*, 120, 123, 124, 125, 127, 128, 129, 130, 132, 133*, 134, 141, 145, 146, 147*, 151, 154*, 155, 156, 157, 165*, 171, 172, 173, 174, 175, 177, 178, 181, 183*, 185, 186, 189, 190, 193, 194, 195, 197, 202, 203, 209, 212, 213, 215.

Topics for Research

There is much still to be learned about textile luster in spite of over 50 years' use of commercial processes for improving that quality in yarns and fabrics and over 100 years of more or less sporadic study of the subject. Perhaps the importance of luster has not been fully recognized in the textile industry, as evidenced by the following statement in the fifth edition of Matthew's *Textile Fibers:*

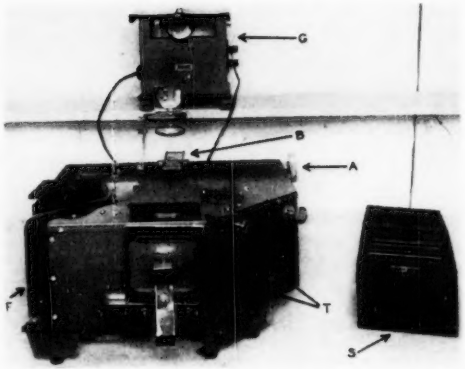

FIG. 30. *Hunter Multipurpose Reflectometer.* G—*Galvanometer.* B—*Balancing scale for reflective photocell.* A—*Nob to move reflectance cell and scale.* T—*Alternate positions for test samples.* F—*Filter disc.* S—*Standard reflecting samples.*

"Luster under certain conditions and for certain uses enhances the value of a textile fiber, but there are instances where a metallic or too bright a luster has militated against the use of a fiber, such as the early rayons. In general, luster is considered an ornamental rather than a necessary quality of a fiber." No exception is taken to the above statement, as far as it goes, but it might be pointed out that the size of the dyestuffs industry today is adequate testimony to the importance of "ornamental rather than necessary" qualities in fibers.

The long history of scientific interest in textile luster certainly does not mean that possibilities for markedly increasing the luster of cotton have been exhausted. Information on the demand for this quality in cotton may intensify work on the problem. Moreover, a better knowledge of fiber properties, improved research techniques, and advances in other branches of scientific knowledge should accelerate progress in this field.

Obviously, this problem will not be solved without extensive research. There may be several answers, each fitting certain applications. The way to higher luster may very likely lie along some avenue not yet considered by those familiar with the subject. The several approaches that are suggested below, therefore, should not be regarded as limiting in any manner the scope of research for improving cotton's luster. They are offered merely as possibilities through which progress might be

made and as a reminder of certain factors which must be considered.

1. Selection and Breeding. The physical properties of cottons of different varieties and of different growth and environments show significant variations. The luster of cottons, both before and after finishing, depends somewhat on those varietal and environmental characteristics. While the importance of functional properties which might require other fiber characteristics may prohibit breeding simply for the purpose of obtaining maximum luster, it behooves both seed breeders and growers to understand more completely all of the fiber properties that affect the marketability of cotton.

Differences of fiber shape that are related to variety, environment, and maturity of growth suggest the possibility of some control of this luster-related factor. Furthermore, certain farming practices might improve the surface smoothness of the cotton fiber, while other advances in agronomy could alter the fiber's content of minerals, waxes, and pectic substances. Even the crystallite orientation is among those physical characteristics which lend themselves to some control by selection of variety and by cultivation practices.

Although the influence of variety and growth on luster may be of a substantially lower order than changes in luster brought about by other means, they are important and warrant further study. Mills and converters may eventually specify certain cottons which by their nature are best adapted to uses in which high luster is desirable. Finishers may yet recognize differences in cottons and thus adapt their processes for optimum results with each type. Studies on variety and growth are not expected to provide the whole answer to cotton's luster needs, but such studies will aid in a better understanding of those cotton fiber characteristics which are related to luster.

2. Influence of Non-Cellulosic Impurities. The amount of non-cellulosic material in cotton varies from 4% to 12%, averaging from 6% to 7%, of the weight of the dry fiber. The amount of this non-cellulosic material, its composition, and its manner of association with the fiber can obviously affect a property like luster which is at least partly dependent on surface character. The waxes, pectins, and minerals which constitute a large part of the non-cellulosic material in cotton are known to influence dyeing characteristics, spinning performance, and even photochemical degradation of cotton. A detailed investigation of the influence of these impurities on luster would be a contribution to the knowledge of this subject.

The study of the influence of the non-cellulosic constituents of cotton should be extended to show whether their removal during processing, including kiering and bleaching, leaves the fiber surface in a roughened condition.

3. Surface Character of the Cotton Fiber. Since light reflection is affected by the nature of the reflecting surface, the surface of the cotton fiber would seem to be a logical subject for thorough investigation. Tools for such studies were unavailable to the early researchers, but today we have the electron microscope, several methods for studying surfaces by absorption and adsorption, and other advanced techniques for examining very small surfaces. Irregularities in fiber surfaces should be evaluated by studying the surface character of cottons known to vary widely in luster, and also by comparing the surfaces of cotton fibers with those of other natural fibers and with those of the synthetic fibers.

4. Crystallite Orientation. The study on fiber surface suggested above, a study on crystallite orientation, and a study on swelling and shape improvement which will be outlined below are all directed toward sorting out and measuring the relative importance of these three factors in producing luster in cotton. The serious objections to early conclusions which gave so much importance to surface reflection and shape have already been noted. Positive rating of the significance of surface, shape, and fibril orientation, as well as knowledge of the exact function of swelling and stretching in luster development, would materially advance our understanding of luster in cotton.

The possible or probable influence of crystallite orientation has been discussed in an earlier section. To separate the effect of the fibrillar structure from the effects of shape and surface will require careful techniques, possibly involving studies of a large number of fibers whose *average* in values of shape, surface, and crystallite orientation can be measured. It might also be profitable to investigate stretching after mild swelling with water or some other relatively weak swelling agent, so that the shape and surface may be changed a minimum amount when crystallite orientation with the fiber axis is improved.

There is a need for further studies of the natural luster of cottons the x-ray angles (orientation) of which differ widely. Data available at present show

that the lustrous Sea Islands and long Egyptians are more highly oriented than American Uplands, and that the dullest Indias and Brazilians have wide-angle orientation. If it can be conclusively proven that the luster differences stem primarily from crystallite orientation rather than from shape or surface differences, the importance of the orientation factor will be made more clear.

5. Swelling and Shape Improvement. From geometrical considerations alone it is apparent that the luster of cottons should be improved by swelling and rounding-out of the fiber and by removal of the convolutions. Shape improvement would have an important effect on both specularly reflected light from the surface and on refracted and subsequently reflected light. Swelling in mercerizing also changes the crystalline-amorphous ratio in cotton, opening the structure and bringing it closer to that of rayon, in which there is less internal interference with the passage of light.

Studies on swelling should include the following topics: (1) detailed comparison of the normal shape, the mercerized-unstretched shape, and the mercerized-stretched shape; (2) an examination of surface differences in mercerized-unstretched and mercerized-stretched cotton; (3) transparency measurements (perpendicular illumination) on pads of fibers prepared from normal cotton, mercerized-unstretched cotton, and mercerized-stretched cotton; (4) an investigation of the relationship between lumen shape and luster.

These are only a few of the studies on swelling that will be found interesting and valuable. Other investigations should be made on the action of various swelling agents, such as acrylonitrile, since their function may throw additional light on the possibly complex function of swelling in mercerizing.

6. Fiber-Surface Polish. The possibilites of fiber polishes should not be overlooked even though it may be difficult to visualize the practical application of such finishes. The effectiveness of a polish is due to the creation of another surface from which light is reflected specularly. Resin chemistry has given us a variety of transparent plastics that might be utilized to form a durable polish film on the cotton fiber. Methods must be developed that will permit the polish to cover each fiber independently and thus avoid the inter-fiber bonding that so often occurs in resin applications.

Fiber-surface polish might conceivably be developed by means more delicate yet more durable and satisfactory than the additive applications proposed above. Chemical modification of the cotton fiber surface suggests the addition of fatty acid or paraffinic groups; in subsequent processing these groups might result in improved fiber surface characteristics. Perhaps in the early stages this part of the study should be confined to determination of luster values of those chemically modified cottons now available.

7. Fabric Construction and Design. The principle of placing fibers in parallel in bundles to be subjected to a minimum of twisting or bending guides the design of fabrics for high luster. This principle has been carried out so faithfully that even the twist factor of doubled yarns has been determined for maximum luster over a wide range of yarn numbers. Patterns and designs are accentuated in fabrics by utilizing the luster characteristics of opposingly orientated surface yarns. Even color is utilized for effects similar to that of "shot silk" in which warp and filling are of sharply contrasting colors.

Research on the influence of fabric construction might first be directed toward learning the limiting factors of construction. In other words, how much of the final luster of a fabric is dependent on the luster of its fibers and how much on construction factors? It is suggested that certain ideal structures, probably simple pads of fibers, be prepared from cotton, mercerized cotton, rayon, and other fibers. By using fibers of the same fineness, by employing sufficient tension to remove all kinks, and by having the pads packed in the same manner, it should be possible to learn more about fiber and fabric influence on luster.

Another way of determining the limiting effects of construction would be by using the brightest available synthetic staples to make a number of typical cotton-type fabrics.

8. Control of Fuzzing. The lasting effectiveness of any luster finish on cotton goods depends in part on the amount of fuzzing after periods of use or after laundering. Fiber ends which are loosened and raised tend to diffuse the lustrous highlights of the fabric. Continuous-filament synthetic fibers have a basic advantage over all short-staple fibers in their freedom from fuzzing because fiber ends can be loosened only by breakage of the filaments. A process which would bind the fibers into the yarns so that they would be less easily brushed up or raised would increase the durability of luster in cottons. The problem is made difficult, however, by the fact that

any binding of the fibers which restricts their free movement usually reduces the flexibility and flex resistance of the fabric and frequently its tensile and tear strength. The solution of the problem may lie partly in the realm of constructional modifications and partly in that of chemical finishes.

9. Use of Fluorescent Materials. Since contrast between dull and brighter yarns enhances the effect of luster, any finish which increases the brightness of either white or colored yarns will accentuate luster even though no increase in specular reflection may be involved. Certain fluorescent dyes, either colored or colorless, absorb light from the non-visible parts of the spectrum, such as the ultra-violet region, and emit light of visible wave lengths. The use of such materials makes white fabrics appear whiter in daylight and causes the colors of dyed fabrics to appear brighter. How far this principle can be carried to increase contrast for luster effects is problematical, but the field is new enough to warrant further study.

10. Improved Mercerizing. After more than 50 years of commercial use and after thorough study by some of the foremost textile scientists, possibilities for improving the mercerizing process in effectiveness and reducing its cost might not appear to be one of the more promising approaches to better luster. Nevertheless, the fact that conversion of the native cellulose in cotton to the mercerized form seldom exceeds 60% to 70% for yarn and 35% to 40% for fabric indicates that there is still room for improvement. Some new wetting agents may be found useful and possibly swelling agents may be developed which act more or less as catalysts for the mercerizing process. Further work on the effect of high tension during mercerization is suggested. High tensions are not used at present, although it is now known that higher than normal tensions increase luster because of mechanical limitations and because cotton which is positively stretched during mercerization has less affinity for dyes than cotton mercerized under just enough tension to prevent shrinkage.

11. Improved Cuprammonium Finishes. The cuprammonium finish as a means of developing luster in cotton has never reached the stage of development which its nature indicates might be possible. If a light cuprammonium finish could be given to each fiber, depositng a film of regenerated cellulose as a smooth transparent coating on the outside of the fiber, luster might be substantially improved without significant loss of other fiber properties. Most of the disadvantages of the cuprammonium finish, up to this time, have been in the changed hand and texture resulting from inter-fiber bonding. The cuprammonium finish, in so far as luster is related to surface reflection, is a treatment which deserves further study.

12. Importance of Reflected and Refracted Light Components. A number of the research studies that have been suggested here are directed toward the improvement of surface characteristics of the cotton fiber on the basis that surface reflection is conceded to be important in luster. Other studies are suggested with the idea that light passing into and through the fiber, and which is subsequently reflected, plays an important part in luster. It would seem reasonable that in the first studies on luster an attempt should be made to learn more about the importance of surface reflection relative to light returning from the interior. One study might include a comparison of the specular intensity of light reflected from mercerized cotton with that reflected from the same mercerized cotton after it has been dyed black so that light passing into the interior will be absorbed. The subjective or contrast luster of the dyed cotton may be greater than that of the undyed cotton, but if the specular intensity, or objective luster, is lower in the case of the dyed fibers, it will mean that there has been a loss of specular reinforcement from light passing into the fibers.

Another way of getting at the importance of light which passes through the fibers would be to study the transparency of fibers mercerized at different tensions. As noted above, luster increases as tension during mercerizing is increased. If light-transmission studies fail to show higher fiber transparency at increased tensions, it would mean that surface reflection (or reflection from a point within the fiber) is the important consideration in luster. In other words, light is not passing completely through the fiber to the opposite surface or to fibers beneath and then being refracted, as is illustrated in Figure 9.

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Moisture Determination in Textiles by Electrical Meters: Part III*

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Abstract

This paper, the third in a series on determining moisture in textile materials by electrical meters, describes tests made on the Moisture Register. The meter tested was designed for wool and when properly used gave results with a precision of ±0.35% moisture, which approaches closely the precision of oven measurement. When used on materials for which it was not intended—namely, cotton sliver and acetate staple—the results were appreciably less precise. In common with other meters tested, measurements are sensitive to temperature changes and the presence of impurities.

IN AN EARLIER PAPER of this series [1] which presented data on the operation of two electrical moisture meters, the Hart and the Steinlite, reference was made to a third meter on which tests had just begun. It is the purpose of this paper to summarize those tests.

The meter referred to was a Moisture Register Model PD–1C–110. It is an alternating-current instrument consisting of two units connected by a flexible, rubber-covered cable. The first unit, the "gun," is a cylindrical tube containing a radio-frequency oscillator tube and accessory circuit components, a spring-and-micro-switch assembly which permits a definite pressure to be applied by the electrodes to the test sample, and a contactor head containing concentric flush electrodes which is pressed against a bulk sample whose moisture is to be determined. The other unit contains the power supply, a microammeter, and a small lamp which lights when the proper pressure is applied by the contactor head.

The microammeter records the unbalance of a tuned circuit caused by a change in dielectric constant of the textile material. Dielectric constant is one of the electrical properties that changes rapidly with change in moisture content; therefore, the latter can be determined from the dial reading through a calibration curve. In order to utilize the marked electrical effect resulting from variation in the dielectric constant and still retain sensitivity, the Moisture Register is available in different models for different textile materials and for different moisture ranges of the same material. The model under test was primarily designed for clean wool in the following forms: bulk, top, skeins, soft fabrics. The principal material tested was white scoured wool skeins (4/8 50's). In addition, tests were run on a second-drawing cotton sliver and acetate staple.

Samples were prepared by the "standard equilibrium method" described in the earlier paper (wetting thoroughly and equilibrating in an air-conditioned room from the thoroughly wet state). After 7 days' exposure to air, conditioned to within ± 1% R. H. and ± 1°F, it was considered that the samples had reached equilibrium. Half of the wool samples were wet with 5% sodium chloride solution instead of water in order to determine the effect of an electrolyte on the meter reading. A semi-quantitative analysis of the salted samples showed that they contained less than 1% of sodium chloride.

A Lucite box 3 in. by 3 in. by 6 in. deep was made to hold the samples during test. After each reading, the sample was removed, shaken loose, and replaced in the box for another reading. For each sample the average of six such readings was recorded. The sample for oven analysis was obtained by combining four quarter-gram portions taken from different

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TABLE I

Temp. (°F)	Average oven moisture (C_o)	Average meter reading	V_X	V_Y	V_{XY}	Slope at $(X, Y)=\beta$	V_o	V_I	V_I/β^2	n
					White scoured wool yarn					
55	7.65	6.4	0.0098	0.005	+0.004	0.80	0.0048	0.001	0.002	6
52	9.72	8.4	0.0065	0.142	−0.003	1.47	0.0085	0.146	0.068	6
52	12.42	13.6	0.0198	0.232	+0.023	2.35	0.0100	0.178	0.032	6
70	9.52	10.5	0.0344	0.122	−0.001	2.30	0.0348	0.124	0.023	6
80	6.10	6.0	0.0059	0.020	+0.005	0.75	0.0013	0.016	0.029	6
						Pooled Values	0.020		0.031	
					Salted wool yarn					
55	7.94	6.9	0.0033	0.014	+0.006	1.08	0.0000	0.008	0.007	6
52	10.06	9.5	0.0066	0.012	+0.004	1.81	0.0044	0.020	0.006	5
52	12.73	17.8	0.0846	1.072	+0.187	4.20	0.0402	0.288	0.016	6
70	9.09	12.2	0.0511	0.630	−0.060	2.88	0.0718	0.802	0.097	6
80	6.00	6.1	0.0131	0.022	+0.068	2.01	0.0000	0.000	0.000	6
						Pooled Values	0.024		0.026	
					Cotton sliver					
55	3.81	23.7	0.0131	0.502	+0.027	0.62	0.088	0.491	1.273	6
52	5.41	29.7	0.0019	1.072	−0.025	0.94	0.029	1.096	1.242	5
52	7.20	44.2	0.0078	8.426	−0.167	2.59	0.072	8.858	1.320	6
70	4.97	29.7	0.0765	1.578	+0.141	1.36	0.000	0.000	0.000	6
80	3.15	22.4	0.0231	0.016	+0.062	0.85	0.000	0.000	0.000	6
						Pooled Values	0.038		0.751	
					Acetate staple					
55	2.28	4.6	0.0986	0.094	+0.060	0.465	0.000	0.066	0.305	6
52	3.74	5.0	0.0026	0.054	0.000	0.667	0.003	0.054	0.121	6
52	5.66	6.7	0.0910	0.066	−0.114	0.871	0.222	0.165	0.218	6
70	3.34	5.2	0.0819	0.064	+0.055	0.971	0.026	0.011	0.012	6
80	1.68	4.2	0.0050	0.026	−0.005	0.424	0.017	0.028	0.155	6
						Pooled Values	0.053		0.135	

positions in the main sample. The precautions previously described to insure maximum removal of moisture were followed in the oven analysis. Samples were conditioned and tested at approximately 54°F, and at 70°F and 80°F to determine the effect of temperature on the calibration curve.

In preparing the calibration curves, an attempt was made to choose the type of coordinates which would result in equal variances at different points on the scale. Rectangular coordinates met these conditions within the limits of the evidence available.

The data were calculated in the same manner as that used in the previous paper—that is, by a separation-of-variance technique. The results are summarized in Table I, the most important columns in this table from the statistical viewpoint being those labeled V_o and V_I/β^2, the oven variance and the instrument variance converted to a moisture content scale, respectively. The values in these columns for any single material have been pooled since there is no conclusive evidence of a trend with moisture content. Complete analysis of the results can be obtained by consideration of these pooled values.

Considering first the oven variances, V_o, it is found that all lie in the same general range, 0.02 for scoured and salted wool yarn, 0.04 for cotton sliver, and 0.05 for acetate staple. These values are all obtained by oven analysis, and variations in electrical properties do not therefore appear. The results for wool duplicate closely pooled V_o values previously reported [1].

When the instrument variances are converted to the moisture scale by dividing by β^2, it is found that the resulting values are 0.03 for both scoured and salted wool yarns, which are of the same magnitude as the oven variances. However, the cotton sliver has a value of roughly 0.75 and the acetate of 0.14. These values are out of line with the other results, but this is not surprising in that the instrument was primarily designed for wool.

From the above indications, the Moisture Register is capable of giving results on a material for which

it is designed with only slightly less precision than that obtainable by oven analysis. In terms of a 95% confidence limit, the moisture read from a properly prepared wool calibration curve would be within approximately $\pm 0.35\%$ moisture, a figure which is in close agreement with data obtained on other meters. This tolerance is almost certainly permissible where a quick moisture test is required. For the cotton and acetate samples tested, the limits would be $\pm 1.7\%$ and $\pm 0.75\%$, respectively.

Figures 1 and 2 show typical calibration curves obtained from these studies. They are of particular value in showing the form of curve but it should be noted from the results that the general flatness does not result in a loss of sensitivity.

The general effects of impurities are similar to those which have been noted previously [2]. Increase of impurities results in a general raising of the calibration line; thus, the use of a calibration line prepared for a pure material will result in an erroneously high indication of moisture when an impurity is present.

The temperature effect is similar to that found for impurities, as is the case with other meters. It is therefore imperative that a correction be made for any appreciable change in temperature. Otherwise, an increase in temperature will be interpreted as an increase in moisture.

Table of Symbols

X	= abscissa of calibration curve, oven moisture (%)
Y	= ordinate of calibration curve, meter reading
V_X	= estimate of variance of X values
V_Y	= estimate of variance of Y values
V_{XY}	= estimate of covariance of X and Y values
β	= slope of calibration curve at average values of X and Y (duplicate determinations)
V_0	= estimate of variance attributable to oven analysis only = $V_X - V_{XY}/\beta$
V_I	= estimate of variance attributable to instrument only = $V_Y - \beta V_{XY}$

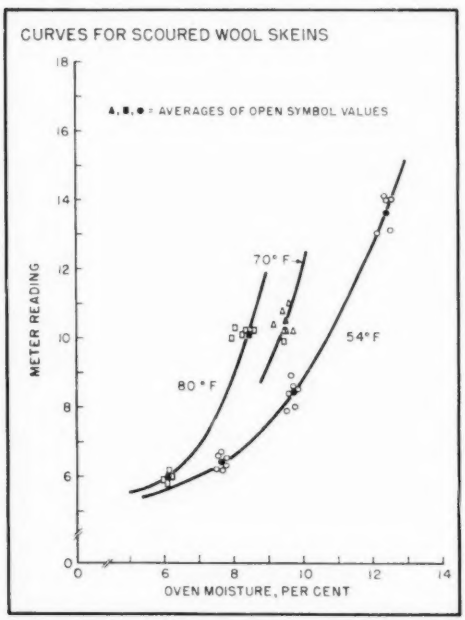

FIG. 1. *Typical calibration curves for scoured wool skeins showing temperature effect. Solid symbols represent averages of open-symbol values.*

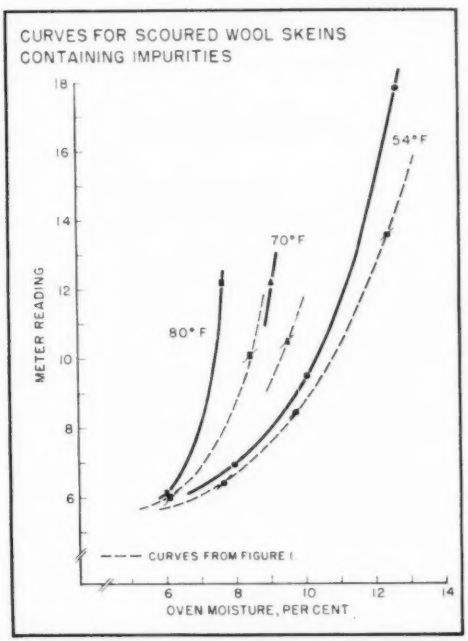

FIG. 2. *Typical calibration curves for scoured wool skeins containing impurities (NaCl). Dotted lines are the curves from Figure 1. Average values only shown.*

$V_I\ \beta^2$ = estimate of instrument variance converted to percent moisture

n = number of readings which made up the average

Acknowledgment

The authors wish to acknowledge with appreciation the experimental contributions of Richard H. Baumann, a senior at Princeton University during the academic year 1948–1949.

Literature Cited

1. Toner, R. K., Bowen, C. F., and Whitwell, J. C., Moisture Determination in Textiles by Electrical Meters: Part I, TEXTILE RESEARCH JOURNAL **18**, 526 (1948).
2. Toner, R. K., Bowen, C. F., and Whitwell, J. C., Moisture Determination in Textiles by Electrical Meters: Part II, TEXTILE RESEARCH JOURNAL **19**, 1 (1949).

(Manuscript received August 19, 1949.)

T. R. I. Annual Meeting

THE TWENTIETH ANNUAL MEETING of Textile Research Institute will be held Thursday, Friday, and Saturday, December 1, 2, and 3, at the Waldorf-Astoria Hotel in New York City.

The theme of the meeting will be "Textile Progress from Fundamental Research."

Four addresses are scheduled for the first day's program:

"Some Recent Studies on Wool," by James H. Wakelin, Associate Director of Research, Textile Research Institute and The Textile Foundation;

"Biochemical Mechanism of Cellulose Breakdown by Microorganisms," by R. G. H. Siu, Research Director, Quartermaster General Laboratories, Philadelphia;

"Recent Researches on Silk Fibroin," by Hugh S. Taylor, Dean of the Graduate School and Chairman of the Department of Chemistry, Princeton University;

"Some Aspects of Fabric Hand," by R. M. Hoffman and L. F. Beste, Technical Division, Rayon Department, E. I. du Pont de Nemours and Company, Inc.

The Friday program will feature the following subjects and speakers:

"Meeting Consumers' Needs in Textiles," by W. E. Coughlin, Director, Textile Laboratory, Good Housekeeping Institute;

"Mill Trouble Shooting and Its Future," by Rene Bouvet, Textile Research Department, American Viscose Corporation;

"Practical Applications of Fundamental Research," by Walter J. Hamburger, Director, Fabric Research Laboratories, Inc.;

"Textile Research Institute Research," by J. H. Dillon, Director of Research, Textile Research Institute and The Textile Foundation;

"Institute Progress," by A. G. Ashcroft, President, Textile Research Institute, and Director of Research, Alexander Smith & Sons Carpet Company, Inc.;

"Textile Progress from Fundamental Research," by Andrew E. Buchanan, Jr., Assistant General Manager, Rayon Department, E. I. du Pont de Nemours & Company, Inc.

On December 1 and 2, luncheon will be served in the Waldorf meeting rooms at 12:45 P.M.

On both of these days, from 9:00 A.M. until 6:00 P.M., the members and guests of the Institute are invited to view exhibits of the latest laboratory-control and testing instruments, as well as other exhibits of interest to those engaged in textile research and the production of textiles. The exhibits will be displayed in rooms adjoining the meeting rooms, and representatives of the manufacturers will be present to explain and demonstrate their products.

Saturday, December 3, will be Open House Day at the Laboratories of the Textile Research Institute and The Textile Foundation in Princeton, New Jersey.

Members and guests will be transported to the Laboratories in Princeton by coach-buses, which will leave the Waldorf at 9:00 A.M. and return at about 4:00 P.M.

T.R.J. to Start New Plan for Furnishing Abstracts to Subscribers in 1950

In January, 1950, TEXTILE RESEARCH JOURNAL *will begin a new method for handling technical abstracts. By arrangement with the Textile Institute, Manchester, England, the Abstracts section of the* Journal of the Textile Institute *will be bound and mailed monthly to the subscription list of* TEXTILE RESEARCH JOURNAL. *Also at this time the current Abstracts section of* TEXTILE RESEARCH JOURNAL *will be discontinued.*

There will be no extra charge to subscribers to TEXTILE RESEARCH JOURNAL *for the new abstracts service.*

Through this arrangement with the British Textile Institute two purposes will be served: (1) simplification of the present abstract situation, in which the multiplicity of abstract services, most of them limited in scope, is confusing to everyone who desires to keep posted on developments, and (2) a broader coverage of the general literature pertaining to textiles will be furnished to readers of TEXTILE RESEARCH JOURNAL.

The collaboration between the Textile Research Institute and the British Textile Institute represents a constructive effort toward reducing the duplication of abstracts appearing both in TEXTILE RESEARCH JOURNAL *and the* Journal of the Textile Institute.

In as much as the latter carries a good coverage of domestic and foreign publications, in both technology and science, it is believed that subscribers to TEXTILE RESEARCH JOURNAL *who are also receiving the* Journal of the Textile Institute *will be able to make good use of this separate copy of the British Abstracts. Business executives also will find it advantageous to have under separate cover a monthly abstracts publication covering the general developments in textiles.*

Subscribers to TEXTILE RESEARCH JOURNAL *who have been receiving T.R.J. abstracts reprinted on one side of the sheet for clipping and filing may, if they wish, subscribe to the new abstract section printed in the same manner. The cost of subscriptions to this service will depend on the total number of such copies required but is estimated at from $5.00 to $8.00. This offer is open only to subscribers to* TEXTILE RESEARCH JOURNAL.

ABSTRACTS*

ANALYSIS: TESTING: LABORATORY METHODS

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Water Absorption

A water-absorbency apparatus. E. C. Jackson and E. R. Roper. *Am. Dyestuff Reptr.* **38**, 397–401 (May 16, 1949).

An apparatus and procedure have been developed for a practical laboratory means of measuring absorptive properties of fabrics which would bear some resemblance to the end use of the fabric. The apparatus and test method are described, typical results are illustrated, and the variables which affect the results are listed. These are: atmospheric humidity, pressure, effect of sample size in relation to plate size, effect of water temperature, effect of negative head variations, and effect of funnel resistance. C.A.A.

Text. Research J. Nov. 1949

Analysis of Chlorine

The spectrographic determination of chlorine in textiles. W. W. A. Johnson and D. P. Norman. *Am. Dyestuff Reptr.* **38**, 361–3 (May 2, 1949).

Preliminary experiments indicated that the lower limit of detection of chlorine by means of a condensed spark source is of the order of 0.5%, or, on an absolute scale, 900 μg. However, this limit is not sufficiently sensitive for determining chlorine pick-up in resin-treated textiles. It was thought that if the chlorine were treated with copper or calcium, the copper chloride or calcium chloride diatomic radical formed might be sufficiently sensitive, but this did not prove to be the case. However, arc runs on mixtures of aluminum powder and mixtures of halogenated organic compounds showed that aluminum-chloride emission spectra at 2610 Å. could be readily observed at high clorine concentrations, and if the arc were operated in a vacuum, as little as 5 μg. of chlorine could be detected as aluminum chloride. The conditions necessary to yield optimum sensitivity and accuracy are described. About 1 sq. in. of fabric is necessary for an experiment, and if a quantitative determination of chlorine is desired, it is necessary to calibrate the observed brightness of the aluminum-chloride bands in terms of mg. per sq. in. of fabric. It is thus possible to determine variations in the chlorine content of fabrics or finished garments, at intervals as close as 1 cm., so that the uniformity of chlorine retention as a function of garment shape or fabric weave can be readily determined. *Cf.* Norman, Johnson, and Johnson, *Am. Dyestuff Reptr.* **37**, 838–48 (Dec. 13, 1948); TEXTILE RESEARCH JOURNAL **19**, 250 (Apr. 1949). C.A.A.

Text. Research J. Nov. 1949

Analysis of Wetting

An index of the water-repellency of textiles from the surface tension of aqueous solutions. H. A. Schuyten, J. W. Weaver, and J.D.

*A list of the periodicals abstracted, the abbreviations used for them, and the addresses of English-language publications is given in the January, 1949, issue, page 46.

Reid. *Am. Dyestuff Reptr.* **38**, 364–6, 368 (May 2, 1949).

In order to study the relative efficiency of various water-repellent compounds and changes in efficiency due to method of application, laundering, and dry cleaning, a method was desired which would be capable of evaluating small differences. Since the water-repellency of the compound itself was desired, it was felt that the measurement should be as independent as possible of the type of cloth used and should measure the surface defects only. Reference is made to the spray test, immersion absorption test, dynamic absorption test, wetting-time test, and the limitations of each. A "rolling drop" method is described and the results obtained are considered in relation to the other methods. The results indicate that any differences shown by the test are due mainly to the fabric construction rather than to the type of compound used or the efficiency of the application. C.A.A.

Text. Research J. Nov. 1949

Anelastic Behavior

Creep and damping properties of polystyrene. J. S. Sauers, J. Morin, and C. C. Hsiao. *J. Applied Phys.* **20**, 507–17 (June 1949).

The anelastic behavior of polystyrene is studied by means of creep and damping capacity tests. These test data, together with additional data from stress-strain studies in tension and compression, are discussed with reference to internal molecular structure. The authors attempt to correlate the results with evidence obtained from x-ray diffraction studies of the stressed and non-stressed specimens.

L. P. Witnauer

Text. Research J. Nov. 1949

Determination of Pentosans in Cellulose

Determination of pentosans in cellulose—simplification of TAPPI standard T450 M44 method. P. H. Teunissen. *Anal. Chem.* **21**, 620–2 (May 1949).

A determination of pentosans by an abbreviated form of TAPPI standard T450 M44 method is discussed. The method is shortened by not adding fresh hydrochloric acid during distillation. A change in the calculation formula is required. A correction factor for the presence of hydroxy-methylfurfural is presented.

Author

Text. Research J. Nov. 1949

Isomerism

The significance of the absence of geometrical isomerism among the diazo aryl-sulphonates, -sulphinates, and sulphones in the structural interpretation of Hantzsch's alleged *syn-* and *anti*-diazosulphonates. H. H. Hodgson and D. Bailey. *J. Soc. Dyers and Colourists* **65**, 231–3 (May 1949).

Geometrical isomerism does not exist among the diazosulfonates, sulfinates, and sulfones. Its nonexistence is bound up with the fact that the only diazo aryl-sulfinate isolated is the labile structural isomeride of the stable diazosulfone, and all previous attempts to prepare diazosulfinates have resulted in the formation of diazosulfones. These facts provide additional evidence in favor of the structural viewpoint that Hantzsch's alleged *syn-* and *anti*-diazosulfonates are really diazosulfites and sulfonates, respectively.

C. Amick

Text. Research J. Nov. 1949

Bursting-Strength Test

A new bursting-strength test apparatus for woven and knitted fabrics and similar materials. H. Sulzer. *Textil-Rundschau* **4**, 49–53 (Feb. 1949).

The author describes a simple device (not an attachment for a strength tester) in which a specimen is held between 2 annular rings and a polished steel sphere is pressed against it. The penetration of the fabric and the pressure are measured accurately. Friction between the sphere and the specimen is eliminated by axial rotation of the sphere during the test. The deformation of the specimen is easier to analyze during bursting-strength tests with expanding rubber diaphragms. The apparatus ranks fabrics in the same relative order with respect to strength and elongation as do strip-breaking-strength tests.

J. F. Krasny

Text. Research J. Nov. 1949

Stress-Strain Apparatus

Stress-strain-time apparatus for fiber testing. C. H. Reichardt, H. Schaevitz, and J. H. Dillon. *Rev. Sci. Inst.* **20**, 509–16 (July 1949).

A constant-rate-of-strain type of stress-strain apparatus for testing individual fibers is described. The apparatus employs a linear variable differential transformer in conjunction with a ring dynamometer. A sensitivity of several mg. is obtainable in load ranges from 1 to 50 g. Greater load ranges are possible by changing the size of the ring dynamometer. Modification of the apparatus for a constant-rate-of-stress application is described.

L. P. Witnauer

Text. Research J. Nov. 1949

Moisture Testing

An investigation of methods of testing for moisture in wool. G. C. LeCompte and H. H. Lipp. *Am. Dyestuff Reptr.* **38**, 484, 512 (June 27, 1949).

An attempt to assess the accuracy of various customary drying procedures. 5 techniques were investigated; scoured wool was the material studied. The conclusions drawn were: (1) toluene distillation appears to be the most accurate of the methods investigated for the determination of moisture in wool, (2) drying of wool with hot air in conditioning or forced-draft ovens gives incomplete results for moisture, (3) conditioning or forced-draft driers might yield accurate results if means were developed for a continuous supply of anhydrous atmosphere. C.A.A.

Text. Research J. Nov. 1949

Test for Nitrates

Diphenylamine test for nitrates in mixtures of cellulose esters. A.

G. Roberts. *Anal. Chem.* **21**, 813–5 (July 1949).

Diphenylamine in sulfuric acid is a sensitive reagent for indicating nitrates by producing a blue coloration. Earlier investigators were limited to nitrates in very dilute aqueous solutions. Uncertainty exists concerning its use in the higher nitrate range and on solid materials. An investigation was made of the speed and strength of color development when solutions containing diphenylamine and water were brought into contact with films cast from mixtures of cellulose esters covering a wide range of nitrate compositions. The color development time is a minimum in the region of 2% to 6% nitrogen and increases at higher and lower concentrations. Water content is important; diphenylamine concentration exerts a minor influence. A suitable reagent for general use over a wide nitrate range contains 0.1 g. diphenylamine, 100 ml. conc. sulfuric acid, and 30 ml. water. Quantitative estimates are possible when films of known nitrate composition are used for comparison. Author

Text. Research J. Nov. 1949

Testing of Sizes

The testing of sizes for continuous-filament yarns of high filament strength. E. Bradbury. *J. Text. Inst.* **40**, T299–310 (May 1949).

Two rapid small-scale methods are described for assessing the weavability of sized continuous-filament yarns of high filament strength, such as nylon. The tape weavability test is an accelerated weaving test on narrow warps, in which potential sources of weaving troubles are created in a more frequent and regular manner than would be obtained in a normal warp, by cutting single filaments on one or more threads at the back rest of the loom. The single-thread filamenting test measures the tendency of a cut filament to peel away from the parent yarn under the influence of bending and rubbing against suitable surfaces, and provides an index of one of the most important aspects of the weaving behavior of yarns of high filament strength. It also is best used as a rapid sorting test to weed out unsuitable sizes, as a preliminary to the more thorough examination of the more promising sizes by the tape weavability test.

Text. Research J. Nov. 1949 L. A. Fiori

Torsional Properties of Fibers

The torsional properties of fibers as criterion of fiber quality. P. A. Koch. *Textil-Rundschau* **4**, 199–211 (June 1949).

$$\text{The angle } \alpha \left(\tan \alpha = \frac{\text{fiber length in cm.}}{\text{fiber diameter in cm.} \times \text{number of turns of fiber}} \right)$$

at which the fiber breaks due to twisting serves as a simple measure of the flexibility, independent of fiber fineness. A small α, corresponding to a high number of turns at break, characterizes a flexible fiber. The determination can be made on a slightly modified twist tester; the exact test method is described. Results for many German synthetic fibers range from approximately 30° for casein through 50°–60° for viscose to 85° for glass. A table showing the specific gravities of all common fibers is included.

Text. Research J. Nov. 1949 J. F. Krasny

CHEMICAL and PHYSICAL RESEARCH

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Abrasion

The effect of abrasion on breaking strength and elongation of fifty-eight clothing fabrics. E. F. Stout and M. B. Moseman. *Am. Dyestuff Reptr.* **38**, 417–19 (May 16, 1949).

Effect of abrasion on breaking strength and elongation was studied on 58 clothing fabrics of cotton, rayon, wool, rayon-cotton, rayon-Aralac, rayon-wool, and rayon-nylon. Breaking strength and elongation determinations were made in warp and filling directions after each 100 strokes, up to a maximum of 500 strokes. Cottons proved to be no better than rayons in resistance to abrasion. Some rayons have been much improved since the war years. The wool and the mixed-fiber fabrics, except for rayon-cotton, withstood abrasion better than other fabrics studied. Rayon-wool and rayon-nylon twills proved superior to all other fabrics studied in several respects. Percentage of elongation decreased steadily with increased abrasion on all fabrics with the exception of two in which percentage of elongation increased after the first 100 strokes and then decreased comparably to that of the other fabrics. C.A.A.

Rotting of Cellulose

Biochemical decomposition of cellulose. C. Bodea, P. L. Muresanu, and E. Precup. *Bul. soc. ştiinţe Cluj* **10**, 37–43 (1948) (in French) (through *Chem. Abstr.* **43**, 3609*e* (May 10, 1949)).

Various N compounds were added to 10-mg. samples of soil containing 0.1 g. of cellulose. After inoculation with cellulose-decomposing microorganisms, the soil samples were incubated for 15–31 days at constant temperature and humidity. In the presence of compounds like alanine, glutamic acid, egg albumin, casein, peptone, and globulin, microbial decomposition was very effective at pH 8 and 7.1 and rather ineffective at pH 5. With urea, betaine, barbituric acid, parabanic acid, and hippuric acid, decomposition was effective at pH 8, 6.9, and 5. Very slow decomposition was obtained when lecithin was used. It seems that H_2O-soluble compounds of N are more effective than insoluble compounds.

Text. Research J. Nov. 1949

Stimulating action of p-aminobenzoic acid on the biochemical decomposition of cellulose. C. Bodea and P. L. Muresanu. *Bul. soc. ştiinţe Cluj* **10**, 137–41 (1948) (in French) (through *Chem. Abstr.* **43**, 3609*e* (May 10, 1949)).

Decomposition of cellulose in moist soil was stimulated by the presence

of 0.1 mg. of *p*-aminobenzoic acid (*I*) in 10-g. samples of soil. The soil samples contained either $NaNO_3$ or glycine (*II*). If *I* was omitted, slower decomposition took place. If sufficient *I* was added to supply as much N as that of the $NaNO_3$ and if the $NaNO_3$ and *II* were missing, very little decomposition took place. These experiments lasted 16–26 days at 4 pH values 8.9, 8, 7.1, and 4.9).

Text. Research J. Nov. 1949

Swelling of Cellulose

Sorption and swelling of cellulose under natural and imposed restraints. W. W. Barkas. *Proc. Tech. Sect., Paper Makers' Assoc. Gt. Brit. & Ireland* **28**, 189–210 (discussion, 211–16) (1947) (through *Chem. Abstr.* **43**, 4009*b* (May 25, 1949)).

After an outline of the molecular and micellar structure of cellulose and of the reasons for the hygroscopic nature of the individual cellulose chain molecule, the sorption and swelling of the natural material as found in cotton, wood, and paper are described. It can be proved that both the sorption and swelling, results from a given vapor-pressure rise, must be sensitive to applied stresses. The effects of restraints arising from either internal or external causes are discussed. The sensitivity of sorption to stress in a plastic material provides a plausible explanation of the sorption hysteresis found in cellulose and other fibers. The relation between vapor pressure, H_2O content, swelling, and applied directional stresses is governed by equations which can be used for calculating the elastic constants of swelling materials and for predicting their behavior under practical conditions.

Text. Research J. Nov. 1949

Oxidation of D-Galactose and Cellulose

Oxidation of D-galactose and cellulose with nitric acid, nitrous acid, and nitrogen oxides. W. W. Pigman, B. L. Browning, W. H. McPherson, C. R. Calkins, and R. L. Leaf, Jr. *J. Am. Chem. Soc.* **71**, 2200–4 (June 1949).

Concentrated nitric acid at 0°C containing nitrous acid derived from the addition of nitrites, nitric oxide, or nitrogen dioxide oxidizes *D*-galactose through the following stages: *D*-galactonic acid (or the gamma lactone), *L*-galacturonic acid (or the gamma lactone), gamma lactone of mucic acid, mucic acid. Cotton linters were treated with concentrated nitric acid containing sodium nitrite for 1 hr. at 0°C, then rotated 3 days at 20–25°C. The fibrous product had a uronic anhydride content of 26.4, 27.2, and 31.3% after 1, 2, and 3 days. Linters activated by swelling with 85% phosphoric acid had a uronic acid content of 60%. If nitrites were not present the uronic acid content was only 26%. A. R. Macormac

Text. Research J. Nov. 1949

Dilatometric Studies

Dilatometric studies of high polymers. I. Second-order transition temperature. H. J. Kolb and E. F. Izard. *J. Applied Phys.* **20**, 564–71 (June 1949).

Second-order transition temperatures obtained from density measurements are reported for various polymers. The relationship of intrinsic viscosity and crystallization, in addition to chemical composition, to the second-order transition temperature is shown. **II. Crystallization of aromatic polyesters.** *Ibid.*, 571–5. A qualitative measure of the rate and amount of crystallization is obtained from density measurements for 3 aromatic polyesters. The effect of immersion media on crystallization is studied.

L. P. Witnauer

Text. Research J. Nov. 1949

Dynamic Measurements

An investigation of the dynamic elastic properties of some high polymers. K. W. Hillier and H. Kolsky. *Proc. Phys. Soc. (London)* **B62**, 111–21 (Feb. 1949).

An apparatus for the investigation of the transmission of sound along filaments at frequencies between 1,000 and 6,000 cycles per sec. is described, both for unstrained specimens and specimens undergoing elongation at a constant rate of increase of strain. Measurements of the dynamic elasticity and damping factors of filaments of polythene, neoprene, and nylon have been obtained, and the correlation of these results with the molecular rearrangements which take place during stretching is discussed. Authors

Text. Research J. Nov. 1949

Dynamic measurements of polymer physical properties. J. W. Ballou and J. C. Smith. *J. Applied Phys.* **20**, 493–502 (June 1949).

Three methods are described for investigating the dynamic elastic and dissipative properties of high polymers in fiber and film form in the frequency range from 3 to 30,000 cycles per sec. The effect of frequency and physical state on the dynamic characteristics are discussed. Two of the methods are also employed to measure the temperature dependence of the dynamic modulus. L. P. Witnauer

Text. Research J. Nov. 1949

An apparatus to depict the load-elongation of yarn at five cycles per second. F. Breazeale and J. Whisnant. *J. Applied Phys.* **20**, 621–6 (June 1949).

An apparatus is described which presents on an oscillograph screen the load-elongation hysteresis diagram of a length of yarn, extended and released at frequencies from 1.7 to 5 cycles per sec. Growth of the sample as a function of time is automatically plotted. The dynamic-stretch modulus of the sample may be determined at any time by setting an amplifier dial, and by adjusting the vertical displacement of the spot on the oscillograph screen and the length of the specimen. The performance of the apparatus is illustrated with data obtained for tire cords of various constructions.

L. P. Witnauer

Text. Research J. Nov. 1949

Propagation of ultrasonic bulk waves in high polymers. D. G. Ivey, B. A. Mrowca, and E. Guth. *J. Applied Phys.* **20**, 486–92 (June 1949).

The propagation constants of supersonic waves in natural, GR-S, and butyl rubbers are studied in the frequency range from 40 kc./sec. to 10 Mc./sec. and the temperature range from −60°C to 60°C. Approximate values of Young's dynamic modulus and loss factor are computed from these values, under certain assumptions. The results are correlated with law frequency data. L. P. Witnauer
Text. Research J. Nov. 1949

Hydrodynamics of Non-Newtonian Fluids

The hydrodynamics of non-Newtonian fluids. I. R. S. Rivlin. *Proc. Roy. Soc.* (*London*) **A193**, 260–81 (May 27, 1948).

The classical theory of the hydrodynamics of viscous fluids depends upon the assumption of a particular law governing the relationships between the components of stress in a fluid and those of the strain-velocity. This assumption limits its applicability to Newtonian fluids. Here, the most general possible relationships between the stress and strain-velocity components, which can be obeyed by an imcompressible, viscoinelastic fluid, are derived. These relationships also apply to an incompressible, viscoelastic fluid in a steady state of laminar flow. It is shown how equations of motion and boundary conditions can be obtained if these relations are known. Two problems involving laminar flow are discussed in some detail. These are: (1) the torsional motion of a cylindrical mass of fluid, produced by means of forces applied to its plane ends; and (2) the laminar flow of a mass of fluid contained between two coaxial cylinders rotating with different angular velocities. It is found in case (1) that, in general, normal tractions must be applied to the plane surfaces of the fluid, in addition to the azimuthal tractions expected from the classical theory, in order to produce the specified motion. Analogous results are obtained in case (2). These results apply even when centrifugal forces are neglected and so imply a qualitative difference between the behavior of fluids in general and those for which the special case of classical hydrodynamics is valid. Author
Text. Research J. Nov. 1949

Gomberg Reaction

The mechanism of the Gomberg reaction. III. The fallacies of the free radical theory—a reply to D. H. Hey and W. A. Waters. H. H. Hodgson. *J. Soc. Dyers and Colourists* **65**, 347–52 (July 1949).

The mechanism by which a diazo compound is decomposed is very important. In the argument with Hey and Waters, Hodgson states that their assertion that he applied a free radical concept to experimental conditions is contrary to all the facts. Hodgson affirms that he has never supported the hypothesis of the fission of covalent diazo compounds into free radicals. The arguments used by Hey and Waters to refute Hodgson's criticisms of their work are held to be invalid, and their analogy with decomposition of arylazotriphenylmethanes is proven false. C. Amick
Text. Research J. Nov. 1949

Gough-Joule Coefficients

Relationships between Gough-Joule coefficients and moduli of vulcanized rubbers. F. S. Conant, G. L. Hall, and G. R. Thurman. *J. Applied Phys.* **20**, 526–31 (June 1949).

The Gough-Joule coefficients (*a*) at constant stress and (*b*) at constant strain are defined, and methods of measurement of each on vulcanized rubbers are given. It is shown mathematically and experimentally that the ratio of (*b*) to (*a*) is equal to the "tangent" modulus. The quotient of the Gough-Joule coefficient at constant strain divided by the strain are shown to be constants which are independent of the stress-strain-temperature conditions of the test. Experimental data are given for stocks based on Hevea, GR-S, Neoprene GN, butyl rubber, and butaprene. Authors
Text. Research J. Nov. 1949

Isothermal Distillation

The mechanism of isothermal distillation in the porous-disk osmometer. A. T. Williamson. *Proc. Roy. Soc.* (*London*) **A195**, 97–115 (Nov. 12, 1948).

This paper describes the theoretical investigations which have been made in an effort to clarify several well-established but unexplained observations made by previous workers who have carried out experiments by the unusual osmotic-pressure technique known as isothermal distillation. The treatment is essentially thermodynamic, and leads to the derivation of equations which agree with the accumulated experimental evidence while showing how substantial improvements in performance can be achieved by designing the apparatus in accordance with the guidance given by the theoretical study. One of the derived equations stresses the importance of good thermal conduction between the solvent and solution inside the stillhead, while another gives a quantitative relationship between thermostat temperature fluctuations and osmotic-pressure errors. A description is given of the essential features of the experimental apparatus which has been built for the application of these theoretical advances to the measurement of the molecular weights of high polymers. Author
Text. Research J. Nov. 1949

pH

The limitations of the "internal pH" concept in textile chemistry. J. A. Kitchener and P. Alexander. *J. Soc. Dyers and Colourists* **65**, 284–5 (June 1949).

A rebuttal of the theory proposed by L. Peters and J. B. Speakman on the combination of wool with acids, which appeared in *J. Soc. Dyers and Colourists*, Feb. 1949, p. 63. Kitchener and Alexander state that unlike the neutralization of a soluble base, in which only the hydrogen ion takes part, the combination of an acid with an insoluble protein requires the entry into the fiber of an anion as well as a hydrogen ion. Consequently, the product obtained

due to the activities of the hydrogen ion and the anion rather than any pH function determines the position of equilibrium. This concept, obvious from electrical considerations, is in our view the key to both this problem and to a theory of dyeing. In Peters' and Speakman's reply it is stated that because no other procedure was possible it had been customary to show the amount of combined acid and alkali as a function of the measured pH of the solution outside the fibers, with the result that there had been an unfortunate tendency for many workers to overlook the fact that the internal and external pH values are not, as a rule, identical. Ability to determine internal pH, therefore, has brought order out of chaos.

Text. Research J. Nov. 1949 C. Amick

Polymerization

Studies in polymerization. II. A method for investigating the relation between molecular weights and intrinsic viscosities of polymers, and its application to polystyrene. C. H. Bamford and M. J. S. Dewar. *Proc. Roy. Soc.* (*London*) **A192,** 329–39 (Feb. 18, 1948).

A simple method for investigating the relationships between intrinsic viscosity and molecular weight of vinyl polymers is described. Unbranched polystyrene is found to obey Houwink's law with an exponent of 0.65. Equations are given for calculating the number-average degree of polymerization and molecular weight distribution in unfractionated polymers. It is pointed out that a method is now available for the preparation of polymers with known molecular weights and distribution. The absolute value of the velocity constant for the transfer reaction between styrene and CCl_4 at 60°C is calculated. Authors

Text. Research J. Nov. 1949

Polymerization in the solid state. E. Miller, I. Fankuchen, and H. Mark. *J. Applied Phys.* **20,** 531–3 (June 1949).

Polymerization in the solid state is indicated for ε-carbobenzoxy-α-carboxyl-l-lysine anhydride from an x-ray diffraction study of monomer and polymer. The powder pattern for a sample which was allowed to stand for 1 yr. at room temperature is similar to that for polyparbobenzoxy-lysine prepared by bulk polycondensation at the melting point. A structure is proposed for the crystalline monomer from x-ray diffraction data and optical properties which would involve a relatively small entropy change on polymerizing in the solid state.

L. P. Witnauer

Text. Research J. Nov. 1949

Effective Pore Size and Water-Repellency

The measurement of the effective pore size and of the water-repellency of tightly woven textiles. F. E. Bartell, W. R. Purcell, and C. G. Dodd. *Discussions Faraday Soc.* **1948,** 257–64 (through *Chem. Abstr.* **43,** 3623*c* (May 10, 1949)).

Effective pore radii of 6–100μ are measured by a modified "pressure displacement method" in which the sample is saturated with a liquid forming 0 contact angle (95% denatured alcohol or mineral oil). The water-resistance (P_w) is the minimum pressure required to force H_2O into and through pores of radius r, and is determined with apparatus similar to that of Slowinske (*C.A.* **35,** 1233[8]). Water-repellency is measured by the advancing contact angle (θ^A_w) of H_2O against the fabric, and $\cos \theta^A_w = P_w \cdot rg \cdot 2s$, where g is the acceleration of gravity and s is the surface tension of H_2O. P_w depends upon both water-repellency and r, and data show the effects of the same treatment on different fabrics and of different treatments on the same fabric.

Text. Research J. Nov. 1949

The diffusion of moisture and heat through textiles. P. S. H. Henry. *Discussions Faraday Soc.* **1948,** 243–57; cf. *C. A.* **34,** 3560[6] (through *Chem. Abstr.* **43,** 3623*e* (May 10, 1949)).

Math. The diffusion of moisture and heat through a porous, absorbent body, such as cotton in bulk, is treated as 2 coupled diffusion processes. Simplifications occur where the coupling is very weak or very strong, where the rates of the elementary processes are very different, or where only one variable is of interest. Nomograms are provided to simplify numerical treatment, and the theory is applied to compressed cotton fibers over a range of temperatures and humidities and at 2 values of package d.

Text. Research J. Nov. 1949

Action of Pyridinium Compounds on Rayon

Action of quarternary pyridinium salts of chloromethyl ethers of polyols on regenerated cellulose. J. Lichtenberger and L. Martin. *Textiles* **1947,** No. 3, 127–37; *Chimie & industrie* **59,** 273 (1948) (through *Chem. Abstr.* **43,** 4010*a* (May 25, 1949)).

Polychloromethyl ethers of polyols, in the form of quarternary pyridinium salts, react with regenerated cellulose fibers, decreasing appreciably the degree of swelling and improving the physical properties. The reaction is carried out for 15 min. at 120°–30°C. To avoid degradation due to the acidity of the impregnating solutions, the latter are slightly buffered with AcONa. The number of and the distance between the reactive groups of the quaternary salts definitely affect the results of the treatment.

Text. Research J. Nov. 1949

Stiffness of Rubbers

Time and stress effects in the behavior of rubber at low temperature. J. R. Beatty and J. M. Davies. *J. Applied Phys.* **20,** 533–9 (June 1949).

A study is made of the increase in stiffness of rubber-like materials at temperatures near −25°C and under a shear stress of approximately 148 p.s.i. Correlation of elasticity measurements with x-ray diffraction data shows that crystallization is probably responsible for the increase in stiffness. The effect of vulcaniza-

tion, carbon black, temperature, and stress on the rate of change of stiffness is discussed. A comparison of natural and synthetic rubbers is given, and the effect of mixing various synthetic rubbers with natural rubber on the crystallization of the latter is studied.

L. P. Witnauer

Text. Research J. Nov. 1949

Stretch Versus Orientation

X-ray diffraction studies of the stretching and relaxing of polyethylene. A. Brown. *J. Applied Phys.* **20**, 552–8 (June 1949).

The effects of various amounts of stretch on the orientation of the crystallites in polyethylene at room and at elevated temperatures are studied. Results obtained are compared with the stress-strain behavior of the polymer. Disorientation of the crystallites upon relaxation of the stretched material at elevated temperatures is also studied.

L. P. Witnauer

Text. Research J. Nov. 1949

Transition Temperature

Transition temperature of methyl methacrylate polymers at ultrasonic frequencies. T. F. Protzman. *J. Applied Phys.* **20**, 627–30 (June 1949).

The velocity of sound in methyl methacrylate polymers (Plexiglas) has been measured with high precision at temperatures from 24°C to 90°C and at frequencies from 3 to 11 megacycles by optical diffraction methods. A detailed study of the variation of the velocity of sound with temperature revealed a new type of transition in the neighborhood of 60°C, which is tentatively attributed to a change in the mode of molecular motion.

L. P. Witnauer

Text. Research J. Nov. 1949

Theory

The mechanism of diazotization and of nitrosation. H. H. Hodgson and W. H. H. Norris. *J. Soc. Dyers and Colourists* **65**, 226–31 (May 1949).

Theories on the mechanism of diazotization are given: (1) the amine-salt theory, (2) the theory of proton participation, and (3) the theory that protons are not only unnecessary but in some cases injurious. The authors consider the essential mechanism of diazotization and of nitrosation as that of a generalized aldol condensation, which takes place between undissociated nitrous acid and (*a*) the free aromatic amine or (*b*) a phenol or a secondary or tertiary amine. The role of acid, if present, is to facilitate elimination of water and, in the case of diazotization, to convert the nitrosamine initially formed into the corresponding diazonium salt. C. Amick

Text. Research J. Nov. 1949

Viscoelastic Properties

Propagation of audiofrequency sound in high polymers. R. S. White, B. A. Mrowca, and E. Guth. *J. Applied Phys.* **20**, 481–5 (June 1949).

Dynamic viscoelastic properties obtained from velocity and attenuation measurements in the frequency range of .5–5 kc. and in the temperature range of −5°–90°C are reported for butyl and GR-S gum stocks. L. P. Witnauer

Text. Research J. Nov. 1949

Viscose Process

Hindrance to viscose formation as a result of the properties of individual fibers and the pulp sheet. R. Bartunek. *Das Papier* **2**, 442–5 (1948) (through *Chem. Abstr.* **43**, 3611*b* (May 10, 1949)).

Inhibited viscose formation, as manifested by poor filterability, is traced to insufficient delignification and to incomplete bleaching of the individual fibers. Incomplete mercerization is correlated with unfavorable qualities of the pulp sheet. Lignin residues may cause marked resistance to solution. The floating tendency manifested by certain spruce sulfite sheets during the steeping process is due to unusual "cloud formations" in the pulp. Tests are outlined which warn of future filtration difficulties. When a beech sulfite pulp shows too great a surface absorptive capacity and too low a rigidity, its usefulness in viscose formation is highly questionable. The viscose manufacturer can seldom remedy these defects, which become problems of the pulp manufacturer. Pulp homogenizing prior to its thickening is recommended.

Text. Research J. Nov. 1949

Action of Alkalies on Wool

Action of alkalies on wool. III. Action of alkalies on deaminated wool. R. Cockburn, B. Drucker, and H. Lindley. *Biochem. J.* **43**, 438–44 (1948); cf. *C. A.* **39**, 5494[8] (through *Chem. Abstr.* **43**, 4017*c* (May 25, 1949)).

Deaminated wool, like untreated wool, gives rise to lanthionine when heated with mildly alkaline buffers to 100°C. At room temperature, however, and with stronger alkalies deaminated wool, unlike untreated wool, does not give rise to lanthionine.

Text. Research J. Nov. 1949

Antibacterial Agents on Wool

Affinity of water-soluble substances to wool and their antibacterial activity. R. Fischer, S. Seidenberg, and U. P. Weis. *Helv. Chim. Acta* **32**, 8–17 (1949) (in German) (through *Chem. Abstr.* **43**, 4017*d* (May 25, 1949)).

Strips of plain wool (1 g.) are wet with warm water and placed for 1 min. at about 75°C in 10 cc. of a solution of gram stain I (about 0.05 g. gentian violet) in 20 cc. of water, then thoroughly washed and rinsed. They are then similarly dyed in gram stain II (0.05 g. I), washed, and extracted with boiling alcohol, again dyed with gram stain III (0.01 g. basic fuchsin), and rinsed. The wool is gram-negative under these conditions but is gram-positive when stained at 20–30°C. The affinity for wool of wetting, detergent, mothproofing, and disinfecting agents was determined from the increase in weight of wool strips (10 g. ± 0.01) dyed in the presence of 2 g. of the test substance in 500 cc. of water at 90°C for 10 min., in both neutral and acid solution. The greater the affinity for wool, the

greater was the antibacterial activity for anion-active substances. The one anion-active exception has a higher acid affinity to wool than neutral; so on the basis of the exchange-absorption theory (*cf.* Dubos, *C.A.* **41**, 5583*a*) this is expected.
Text. Research J. Nov. 1949

Stabilized Wool

Shrinkage control of wool-chlorination processes. J. Epelberg. *Am. Dyestuff Reptr.* **38**, P526–8, P533–4 (July 11, 1949).

Treatment of Army socks to prevent felting doubled their life. The author states that any treatment which reduces the differential friction effect of the heel surfaces or modifies the elasticity or elastic recovery of the fibers is more or less effective in overcoming felting. The enzyme, alcoholic-potash, Drisol (sulfuryl chloride), Durlana and Koloc (thermoplastic rubber-like compounds), thermosetting-resin, and chlorination processes are discussed. Consideration is given the chlorination method and the Protonized process, which makes use of a combination of sodium sulfamate and hypochlorite to form sodium chlorosulfamate, a product which gives a much lower exhaustion of chlorine. The possibility of giving wool two treatments instead of one to accomplish a certain result is mentioned and some excellent arguments are given. C.A.A.
Text. Research J. Nov. 1949

BLEACHING: DYEING: FINISHING

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Chemistry of Bleaching

Present status of the chemistry of bleaching. H. W. Giertz. *Cellulosa och Papper, SPCI* **1908–1948**, 326–38; *B.I.P.C.* **19**, 301 (in Swedish) (through *Chem. Abstr.* **43**, 3614*a* (May 10, 1949)).

Theoretical aspects of bleaching with Cl, hypochlorites, ClO_2, and $NaOCl_2$ are discussed, including the chemical action of the reagents on lignin and the carbohydrate constituents of the pulp. The effect of bleaching on pulp quality is considered.
Text. Research J. Nov. 1949

Fluorescent Bleaching

Fluorescent bleaching. A. Landolt. *Am. Dyestuff Reptr.* **38**, P353–6 (Apr. 18, 1949).

The application of 6,7-dioxycoumarin to semi-bleached flax yarn, with a resultant whitening effect, appears to have been the original experiment (1929) on fluorescent or chemical bleaching. This was followed 5 yrs. later by use of a stilbene derivative, 2 yrs. later by an umbelliferone compound, and since 1940 by a number of compounds. Several laws governing fluorescence as an optical phenomenon are discussed briefly. The properties required of a satisfactory commercial "fluorescent bleaching" agent are: it must have an affinity for textile fibers; it must show fluorescence of the appropriate colors; it must in itself be colorless; and it should have good fastness. Fluorescent bleaching agents suitable for cotton, wool, nylon, natural silk, and acetate rayon are discussed and 6 are named —*i.e.*, Blankophor B, R, and WT; Tinopal BV; and Uvitex RS and WS. C.A.A.
Text. Research J. Nov. 1949

Optical Bleach

Organic fluorescent dyes and their technical application. Optical bleach. S. Petersen. *Angew. Chem.* **61**, 17–19 (1949) (through *Chem. Abstr.* **43**, 4015*b* (May 25, 1949)).

A review of toners, with emphasis on derivatives of stilbenediaminesulfonic acid and substantive benzimidazoles. 26 references.
Text. Research J. Nov. 1949

Peroxide Bleach

Bleaching goods for dyeing and finishing in the continuous open-width peroxide system. J. L. Moore. *Am. Dyestuff Reptr.* **38**, P497–9, P504 (June 27, 1949).

The steps of the open-width J-box continuous process are essentially as follows: singe, desize, mercerize, caustic treatment, wash, peroxide treatment, wash, dry, dye and finish. These subjects are discussed in some detail. The hydrogen-peroxide concentration varies from $\frac{1}{2}\%$ to $1\frac{1}{2}\%$ of 35% hydrogen peroxide, depending upon the cloth construction, weight of fabric, and quality of the cotton used in its manufacture. Sodium silicate is an important addition, playing a multiple role: it fixes pH values in the range of effective bleaching, it is the only alkali which gives good peroxide stability in the alkaline pH range, and it has a deactivating effect on catalytic materials present in plant waters, cloth, etc. C.A.A.
Text. Research J. Nov. 1949

Textile Printing Emulsions

Pigmented emulsion for textile printing. D. Cimma. *Papers of ATT* **4**, 107–10 (June 1949).

A brief but up-to-date discussion of the many applications of pigmented emulsions in textile printing.
Text. Research J. Nov. 1949 L. A. Fiori

Jig Housings

Jig dyeing and the value of housings. New York Section, A.A.T.C.C. *Am. Dyestuff Reptr.* **38**, P442, P444 (May 30, 1949).

The jig is not as simple as it seems. The jig dyer must see to it that the roll of cloth is even so that it will run straight and true and that the edges are not permitted to cool off more than the center of the roll. The method of dyeing is probably determined by the end use of the fabric; salt-controllable dyes should be dyed with gradual additions of salt at each end of the batch from the third end on. Housing enables the goods to be held at uniform temperatures from center to selvage, eliminating dirt and simplifying work. C.A.A.
Text. Research J. Nov. 1949

Dyeing Tubular and Warp Knit Textile Fabrics

Dyeing tubular and warp knit textile fabrics. F. A. Alter. *Tex-*

tile Age **13**, 7, 10, 11, 14, 18 (June 1949).

A discussion of the methods and difficulties to be overcome in dyeing knitted fabrics composed of cotton, wool, nylon, and other synthetics. Distortion caused by tension is one main problem. A. L. Landau

Text. Research J. Nov. 1949

Metals in Tippy Dyeing

Metals in tippy dyeing. Anon. *Am. Wool and Cotton Reptr.* **53**, 14, 17 (May 26, 1949).

Results of an investigation into the causes of metal contamination of dye baths and the effect of metals upon wool fleece. Different metals cause different shades of tip and body of fleece, as the metals tend to concentrate in the tips. Leveling agents are recommended to reduce or eliminate uneven dyeing. A. L. Landau

Text. Research J. Nov. 1949

Moiré Finishing

New developments in moiré finishing. H. A. Holterhoff. *Papers of AATT* **4**, 117–23 (June 1949).

Following a general description of the moiré process, the author describes in detail the effects of moiré finishing on many types of fabric, such as irridescent viscose and acetate taffetas, tissue failles, and nylon taffetas. New developments here and abroad, a review of some of the outstanding new patents—notably the "H-process"—and remedial measures for so-called "no-match" pieces are included.

Text. Research J. Nov. 1949 L. A. Fiori

Treatment of Casein Fibers

Effect of after-treatment upon wet strength of formaldehyde- and chrome-treated casein fibers. H. Nitschmann, L. Karasoy, and R. Signer. *Textil-Rundschau* **4**, 182–6 (May 1949).

When dry-spun formaldehyde- and chrome-treated casein fibers were heated in a 1:50 bath, the pH of the water was changed to 4 or less. The effects of various bath compositions were studied: the wet strength of the fiber was greatest when the bath pH was 5–6, when formaldehyde was added to the bath (no increase in wet strength when more than 1.2% formaldehyde was added), when the treatment was conducted at 70°–90°C for 20 min., and when acetate buffers were used. The authors attempt to explain these findings and conclude that addition of formaldehyde to the hot bath may prevent a hydrolysis of the formaldehyde attached to the protein and that formaldehyde possibly reacts with the incorporated chrome complexes. J. F. Krasny

Text. Research J. Nov. 1949

Scouring Wool

Low-temperature wool piece-goods scouring with a synthetic organic detergent. A laboratory evaluation. O. M. Morgan and J. E. Walters. *Am. Dyestuff Reptr.* **38**, P374–7 (May 2, 1949).

The use of synthetic detergents in conjunction with neutral or slightly alkaline salts such as sodium chloride or sodium bicarbonate in the removal of emulsified mineral oil lubricants from wool piece-goods is discussed. The use of suitable synthetic detergents has made it possible to lower the scouring temperature and maintain efficiency. The addition of sodium chloride enables satisfactory scouring to be achieved at temperatures as low as 50°F. Higher concentrations of scouring materials are needed in the cold scouring method than in the hot, but the higher cost is not prohibitive. The authors used 80°F for the cold scouring and 120°F for the hot scouring. Cost data at these two temperatures are included.

Text. Research J. Nov. 1949 C.A.A.

FIBERS: YARNS: FABRICS: MECHANICAL PROCESSES

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Bulrush as a Textile Plant

Bulrush as a textile plant. F. Szymanek. *Textiles* **1947**, No. 2, 151–64; No. 3, 141–60; *Chimie & industrie* **59**, 273 (1948) (through *Chem. Abstr.* **43**, 3621*d* (May 10, 1949)).

The yield of tow is higher than that of most plants. The degumming costs, while fairly high, are lower than for the other fiber plants. Operations are much simpler. The inferiority of bulrush tow as compared with jute tow lies chiefly in the loss of strength when wet. The fineness of well-treated bulrush is comparable to that of jute, and its strength is similar to that of low-grade jute.

Text. Research J. Nov. 1949

A New Fiber—Celcos

Celanese Corp. of America introduces new fiber, Celcos. Anon. *Textile Age* **13**, 44, 47 (June 1949).

Celcos, a new synthetic fiber, is said to combine the best features of acetate and viscose fibers. The synthetic staple is available in various lengths, filament sizes, and lusters. It is more moisture-absorbent than acetate and less than viscose, less thermoplastic than acetate, and can be blended and cross-dyed easily. A. L. Landau

Text. Research J. Nov. 1949

Hackling of Flax

Yield of flax-hackling machines. W. Rohs. *Textil-Praxis* **4**, 166–70 (Apr. 1949).

Flax of reasonably homogeneous quality was hackled, with systematic variation of the number of passages, pin density, pin penetration, rate of pin travel, movement of heads, and weight of fiber per head. The effect of these factors on the yield of tow and line is discussed.

Text. Research J. Nov. 1949 J. F. Krasny

Vicara

Vicara. G. R. Wildermuth. *Papers of AATT* **4**, 111–16 (June 1949).

After a brief description of the manufacturing process of Vicara, the author outlines in general terms physical and chemical properties, bleaching and dyeing characteristics, and adaptability to the cotton, worsted, woolen, and tow-to-top systems. L. A. Fiori

Text. Research J. Nov. 1949

Properties of Yarns from Mixed Fibers

The electrical resistance of yarns made from mixed fibers, and its use in measuring the moisture conditions of these yarns. J. W. S. Hearle and E. H. Jones. *J. Text. Inst.* **40**, T311–37 (May 1949).

Initial assumptions are made concerning the resistance of a yarn of one type of fiber, the application of the parallel law of resistance to yarns of two types of fibers, and the relation between the individual and total moisture contents. Equations are derived which relate the resistance of a yarn of known amounts of two types of fiber to its total moisture content and to the properties of yarns made from the pure fibers. It is shown that there is good agreement between the theoretical equations and the experimental results. Applications of the results to the Shirley Electrical Hygrometer and the Shirley Moisture Meter are discussed briefly. Experiments are described in which the resistances of yarns of cotton, viscose staple, and wool and of yarns containing various proportions of cotton mixed with one of the other two fibers are measured. L. A. Fiori

Text. Research J. Nov. 1949

Slub Yarn Device

Versatile device for Himalaya, slub yarn. Anon. *Textile Bull.* **75**, 50, 52 (July 1949).

A device applicable for installation on standard spinning frames and used to produce Himalaya and slub yarns is described and illustrated. The device is based on the intermittent acceleration and deceleration of the center and back drafting rolls and is capable of producing a wide variety of patterns and effects.

A. L. Landau

Text. Research J. Nov. 1949

Bonded Fabrics

Non-woven or bonded fabrics. J. Bromley and G. H. Elliot. *Textile Recorder* **67**, 77–9 (July 1949).

A general description is given of (1) the commercial bonded fabrics in use, (2) the most promising fields of employment in terms of end usages, (3) the conventional finishing treatments which can be applied to these products, and (4) special finishing treatments necessary for the successful manufacture of abrasive cloths, oiled cloths, water-repellent fabrics, and filtration fabrics.

Text. Research J. Nov. 1949 L. A. Fiori

Moss Crepe Weaves

The design and production of rayon moss crepes. Part 1. A. T. C. Robinson. *Silk and Rayon* **23**, 102, 104, 106, 108 (Jan. 1949); **Part 2, 23**, 251–2, 254, 256, 258 (Feb. 1949); **Part 3, 23**, 382, 386, 388, 390, 392, 394 (Mar. 1949).

This discussion deals comprehensively with the designing of moss weaves, together with the planning of these weaves in order to avoid twill effects and other horizontal, vertical, or diagonal lines. Such limitations are outlined which would adapt these weaves within the capacity of ordinary dobby looms. Complete weave plans with many illustrative designs are given.

Text. Research J. Nov. 1949 L. A. Fiori

Weaving Tire Cord

Weaving defects in rayon tire-cord fabrics. J. J. Sussmuth. *Rayon and Synthetic Texts.* **30**, 65–6 (June 1949).

Failure to reduce tension in the shuttle causes closely woven selvages, together with one of the worst defects of rayon tire-cord fabric, known as "bagginess"—a slack center and tight sides. Other defects, such as sloughing-off, long ends, knots, overhanging edges, etc., are described and remedial suggestions are given. L. A. Fiori

Text. Research J. Nov. 1949

Cloth Inspection Machine and Uniformity Meter

Cloth inspection machine and uniformity meter built at I.T.T. Anon. *Textile Inds.* **113**, 90, 91, 225 (June 1949).

Newly designed cloth inspection machine permits inspection of continuously moving fabric which appears as a series of stationary panels. An area of 18 in. of cloth is viewed in a mirror which tracks the cloth at identical speeds and then returns to pick up the next successive area. Variable speed controls permit adjustment of cloth speed ranging from 20 to 60 yds. per min. The newly developed uniformity meter is designed for testing purposes rather than for production control but will test sliver, roving, or yarn for uniformity of structure, determined as the weight per unit length. The material to be tested passes between 2 condenser plates, causing the dielectric strength of the condenser to vary in relation to the mass of fiber. Yarn is tested at 5–10 ft. per sec., roving and sliver at 3–6 in. per sec. A graph chart of the variation is recorded automatically. A. L. Landau

Text. Research J. Nov. 1949

General Outline of Carding

General outline of carding. R. Z. Walker. *Textile Bull.* **75**, 54, 56, 57 (June 1949).

Discussion of the carding practice. Card production is limited by the stock being processed, both in staple length and grade. Good carding is dependent upon even picker laps, level cards, firm mill floors, and proper atmospheric conditions.

A. L. Landau

Text. Research J. Nov. 1949

High Drafting in Worsted Spinning

High drafting in worsted spinning. Anon. *Fibres* **10**, 203 (June 1949).

A brief description of the high-draft systems existing for worsted spinning. L. A. Fiori

Text. Research J. Nov. 1949

New Aluminum Spinning Spindle

Whitin's new "Alumi-Sheath" spindle. Anon. *Whitin Rev.* **16**, 7–10 (May–June 1949).

A new metallic top spindle for paper tubes is described Essentially, the

new design consists of a short heat-treated steel blade with a special enlarged top, an aluminum sheath bored at the bottom end to be a press fit onto the top of the steel blade, and a chromium-plated steel whorl that is press-fitted over the bottom end of the aluminum sheath. It is used in conventional bolsters and cases and can be adapted to the new wood tubes as well as to the paper tubes. L. A. Fiori
Text. Research J. Nov. 1949

SKF Roller Bearing Spindles

Installation and maintenance of SKF roller bearing spindles. Anon. *Whitin Rev.* **16**, 30–5 (May–June 1949).

General instructions for the installation and maintenance of SKF roller bearing spindles with standard bolsters, brake-ring bolsters, and for spindles for silk and rayon are discussed briefly. L. A. Fiori
Text. Research J. Nov. 1949

MISCELLANEOUS

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Alginate Harvesting Methods

Alginate for industry. Anon. *Text. Mercury and Argus* **121**, 17–18 (July 1949).

A short account describing the various methods devised for gathering the seaweed used as a raw material for the synthesis of alginate fiber.
Text. Research J. Nov. 1949 L. A. Fiori

Method of Measuring Cross-Sectional Variations in Slivers

Measurement of cross-sectional variations in slivers. Anon. *Fibres* **10**, 254–6 (July 1949).

A method is described of measuring cross-sectional variation of woolen slubbing, cotton roving, and insulated wire. It employs pneumatic principles interpreted in terms of manometer readings. In the case of cotton roving, high correlations between pneumatically measured values and directly measured values of weight per unit length have been obtained with two sizes of roving. Illustrated. L. A. Fiori
Text. Research J. Nov. 1949

Mouton

Processing of wooled sheepskins. E. R. Winton. *J. Soc. Dyers and Colourists* **65**, 333–5 (July 1949).

The general processes involved in the production of wooled sheepskin for clothing such as furs or fur coats are discussed. Operations for preparing and tanning the skin, straightening, brushing, and shearing the fur, and dyeing are included.
Text. Research J. Nov. 1949 C. Amick

Neps

Neps. Anon. *Saco-Lowell Bull.* **21**, 27–34 (Apr. 1949).

This brief account dealing with the formation of neps suggests as a remedy the substitution of the blade beater by a carding beater during the picking operation.
Text. Research J. Nov. 1949 L. A. Fiori

Nonionic Compounds

Compounds without active ions; their use in the textile industry. J. P. Sisley. *Teintex* **14**, 53–73 (1949) (through *Chem. Abstr.* **43**, 4016*c* (May 25, 1949)).

A review of the condensation products of fatty acid esters, alcohols, and amides with ethylene oxide. Tables give (*a*) trade names, (*b*) composition, (*c*) state, (*d*) use, and (*e*) country where manufactured.
Text. Research J. Nov. 1949

Plasticizers

The compatibility, efficiency, and permanence of plastizicers. R. F. Boyer. *J. Applied Phys.* **20**, 540–51 (June 1949).

Three properties—compatibility, efficiency, and permanence—of low molecular-weight plasticizers are discussed, and several interrelationships existing between pairs of the properties are given. A preliminary discussion of polymeric plasticizers is presented. The effect of plasticizers on electrical resistance and tensile strength is considered. L. P. Witnauer
Text. Research J. Nov. 1949

Viscose Process

Chemistry of the viscose process. O. Samuelson. *Cellulosa och Papper, SPCI* **1908–1948**, 295–325; *B.I.P.C.* **19**, 345 (in Swedish) (through *Chem. Abstr.* **43**, 3611*a* (May 10, 1949)).

A review of the chemical and colloid-chemical reactions involved in the xanthation of cellulose and the ripening of viscose and the degradation of cellulose during the viscose process. 62 references.
Text. Research J. Nov. 1949

Wool Felts

Evaluation of roll wool felts for arctic footwear. T. M. Plitt Hardy. TEXTILE RESEARCH JOURNAL **19**, 427–35 (July 1949).

Fourteen samples of felts suitable for the tongue, vamp, midsole, and inner sole of shoes were given 15 physical tests in order to evaluate each felt. Results of these tests are tabulated. On the basis of the data obtained from the individual tests, the felts were given a rating in points of excellence; these rating were tabulated. Air permeability and water-vapor permeability did not appear to be affected by water-repellent treatment.
Text. Research J. Nov. 1949

Sequestering

Sequestering agents: their use in textile processing. H. W. Zussman. *Am. Dyestuff Reptr.* **38**, P500–4 (June 27, 1949).

The chemistry and sequestering properties of ethylenediamine tetracetic acid are described. The effect of trace-metals (chemicals present in small amounts) on oxidation, detergency, dyeing, and the improvement noted when a sequestering agent is added are described.
Text. Research J. Nov. 1949 C.A.A.

Sizing

Peanut protein for window shade sizes. J. C. Arthur, Jr., and F. W. Cheng. *Am. Dyestuff Reptr.* **38**, 535–7 (July 11, 1949).

Peanut protein gave uniformly greater elongation of the filling at

break as compared with the commercially-sized samples in which animal glues were used. Consequently, peanut protein appears to be applicable as a sizing material for use in window-shade manufacture and similar operations.
Text. Research J. Nov. 1949 C.A.A.

Wetting Agents

Effect of various surface-active agents on the penetrating power and stability of calcium hypochlorite and bleaching powder solutions. J. T. Scanlan, A. J. Stirton, D. Swern, and E. T. Roe. *Am. Dyestuff Reptr.* **38**, 455–8 (June 13, 1949).

130 surface-active agents have been tested as promoters of wettability for bleaching powder and calcium hypochlorite. Wetting agents which gave satisfactory results with calcium hypochlorite solution and with bleaching powder solutions are listed. Some wetting agents accelerate decomposition of the hypochlorite ion, which may be an advantage under certain conditions.
Text. Research J. Nov. 1949 C.A.A.

Card Feed Plate Maintenance

Maintaining the card feed plate. R. Z. Walker. *Textile Bull.* **75**, 46, 48, 50 (July 1949).

A detailed study of the adjustment and maintenance necessary to assure proper action of the card feed plate. Supplementary subassemblies such as the feed roll, lap roll, feed roll weighting, and selvage guides are described and their importance is reviewed. It is pointed out that a feed roll having bearings worn more than .003 in. cannot operate efficiently. A. L. Landau
Text. Research J. Nov. 1949

New Underframe Cleaner

New underframe cleaner. Anon. *Textile Inds.* **113**, 87–9 (June 1949).

Description of a fan-powered air cleaner employed for cleaning the under-works of a spinning frame. The unit cleans the inside of the frame only and does not remove oily waste or lint. It is claimed that $\frac{5}{6}$ of the manual cleaning of the frame is eliminated. The unit delivers 2 jets of air and travels the length of the frame. A. L. Landau
Text. Research J. Nov. 1949

New Plumbing Disc

The new plumbing disc for New Era spindles. Anon. *Saco-Lowell Bull.* **21**, 38–9 (Apr. 1949).

A new disc especially designed for plumbing the New Era spindles is offered. L. A. Fiori
Text. Research J. Nov. 1949

Spectrophotometer

The elements of color and spectrophotometry. E. W. Rhael. *Am. Dyestuff Reptr.* **38**, P490–5 (June 27, 1949).

This paper is divided into (1) a discussion of the physical theory of color and a demonstration of the validity of its principles, and (2) a description of the construction and operation of the spectrophotometer and a discussion of some of the properties and characteristics of spectrophotometric curves. Curves are given showing the subtractive primaries, effect of concentration of dye, means of cataloging dyes, transmittance of mixtures, and spectral transmittance for several dyes.
Text. Research J. Nov. 1949 C.A.A.

Light Package Uptwister

MUI light package uptwister. Anon. *Platts Bull.* **6**, No. 9, 168–73 (1949).

The salient points and advantages of the MUI uptwister, designed to operate on a wide range of different types of yarns to suit requirements of the hosiery, knitwear, and crepe fabrics markets, are discussed. Illustrated. L. A. Fiori
Text. Research J. Nov. 1949

Loom Research

Loom research—with a review of recent developments. V. F. Sepavitch. *Textile Bull.* **75**, 59, 60, 62 (June 1949).

Review of the research resulting in recent developments of the loom. Improvements in design are stronger beams, fly-wheel motor drives, electronic protection mechanisms, and electronic let-offs. A. L. Landau
Text. Research J. Nov. 1949

Mill Humidification Systems

Five systems available for mill humidification. A. H. Bahnson, Jr. *Textile World* **99**, 104–5, 196, 198, 200, 202 (June 1949).

The five systems of air conditioning and humidification are: (1) direct air humidification by means of atomizers or centrifugal humidifiers, (2) employment of atomizers or self-contained humidifiers in conjunction with window fans, (3) addition of distributing ducts to the system of fans and atomizers, (4) use of central air-conditioning systems delivering controlled atmosphere through ducts, (5) central systems which chill and purify the air in addition to having heat and humidity control. Evaporative cooling is also discussed.
A. L. Landau
Text. Research J. Nov. 1949

Swiss Textile Machinery

Latest types Swiss textile machinery. Anon. *Textile Recorder* **67**, 61–76 (July 1949).

All of the latest-type machines, mechanical improvements, and accessory equipment, from carding through the finishing operations, shown at the Swiss Industries Fair at Basle are described and illustrated. L. A. Fiori
Text. Research J. Nov. 1949

Textile Test Data

A quick and simple method of obtaining the mean and its standard error and the coefficient of variation in textile tests with special reference to the measurement of yarn strength. B. K. Chakrabarti. *J. Text. Inst.* **40**, P370–8 (Apr. 1949).
Text. Research J. Nov. 1949

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